OPTIMIZING SAFETY INVESTMENTS FOR BUILDING PROJECTS IN SINGAPORE

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SUMMARY

The construction industry is increasingly reliant on the voluntary effort to reduce accidents on construction sites. As investments in construction safety cannot be limitless, there is a need for a scientific way to support the decision making about the amount to be invested for construction safety.

The aim of this study is to investigate the financially optimum level of investments in workplace safety for building construction projects in Singapore. To fulfill the aim and four specific objectives, a correlation/regression research design was adopted. Data was collected using multiple techniques (structured interviews, archival data and questionnaires) with 23 building contractors on 47 completed building projects. Data collected were analyzed using various statistical and mathematical techniques, e.g., bivariate correlation analysis, regression analysis, moderation analysis, mediation analysis and extreme value theorem. The analysis revealed some key findings.

(1) This study examined the effects of safety investments on safety performance of building projects. It was found that voluntary safety investments are more effective or efficient to reduce accident frequency rate of building projects than basic safety investments. The result of moderation analysis indicates that there is a stronger positive effect of basic safety investments on accident prevention under higher project hazard level and higher project safety culture level. The result of mediation analysis

for the effect of voluntary safety investments on accident frequency rate shows that the effect of voluntary safety investments is partially mediated by safety culture of the project.

(2) This study investigated the factors determining safety performance of building projects and their interrelationships. The results show that safety performance of building projects is determined by safety investments, project hazard level, safety culture level and the interactions among these variables. The variables and their relationships (including the main effects, interactive effects, and mediated effects) are integrated in a graphic model for determining safety performance of building projects.

(3) This study investigated the costs of accidents to building contractors. Results show that the average direct accident costs, indirect accident costs and total accident costs of building projects account for 0.165%, 0.086% and 0.25% of total contract sum, respectively. It was found that there is a stronger positive effect of accident frequency rate on total accident costs under higher project hazard level.

(4) The optimization model of safety investments was examined in this study. Results show that the financially optimum level of voluntary safety investments could be achieved through the minimization of total controllable safety costs of building projects. It was also found that the financially optimum level of voluntary safety investments varies with different project conditions. Results show that the financially

optimum level of voluntary safety investments of building projects in Singapore is about 0.44% of the contract sum (i.e., when both safety culture and project hazard are at the mean level).

This study contributes to knowledge in construction safety management by discovering that safety performance of building projects is determined by safety investments, safety culture and project hazard level, as well as their interactions. It also found that the effect of safety investments on safety performance varies with different levels of safety culture and project hazard. Moreover, this study further develops the theory behind optimization of safety costs by integrating the impacts of project hazard level and safety culture level of building projects in the analysis. Such knowledge provides the basis for financial decision making to manage construction safety for building contractors.

Keywords: Safety investments, Accident costs, Optimization, Construction safety, Building projects, Singapore.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFR: Accident Frequency Rate

ASR: Accident Severity Rate

BCA: Building & Construction Authority, Singapore

BG: BCA Grade

BSI: Basic Safety Investments

BSIR: Basic Safety Investments Ratio

CS: Company Size

DAC: Direct Accident Costs

DACR: Direct Accident Costs Ratio

DSS: Decision Support System

IAC: Indirect Accident Costs

IACR: Indirect Accident Costs Ratio

LOOCV: Leave-One-Out Cross Validation

MOM: Ministry of Manpower, Singapore

OHS: Occupational Health and Safety

OSH: Occupational Safety and Health

PD: Project Duration

PHI: Project Hazard Index

PPE: Personal Protective Equipment

PRESS: Predicted Residual Sum of Squares

PS: Project Size

SCI: Safety Culture Index

SUB: Percentage of Work Completed by Subcontractors

TAC: Total Accident Costs, TAC = DAC + IAC

TACR: Total Accident Costs Ratio

TCC: Total Controllable Safety Costs, TCC = TAC + VSI

TCCR: Total Controllable Safety Costs Ratio

TSI: Total Safety Investments, TSI = VSI + BSI

TSIR: Total Safety Investments Ratio

VSI: Voluntary Safety Investments

VSIR: Voluntary Safety Investments Ratio

WSH: Workplace Safety and Health

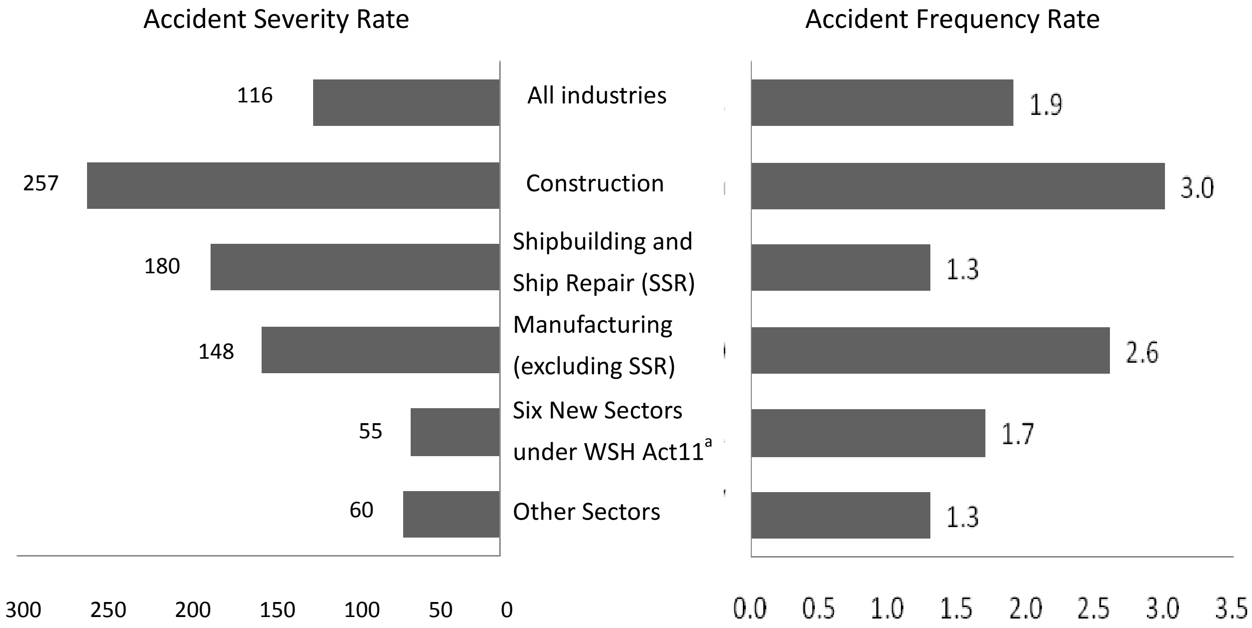
WSHA: Workplace Safety and Health Act

CHAPTER 1: INTRODUCTION

1.1 Background

For the past few decades, efforts have been made by the government and industries in Singapore to address the problem of construction safety. The significance of the construction safety is overwhelming because construction is one of the most dangerous occupations in Singapore (Imriyas *et al.*, 2007a). The construction industry accounts for 29 per cent of the total number of industrial workers, but accounts for 40% of workplace accidents (Chua and Goh, 2004). The Workplace Safety and Health (WSH) statistics published by Ministry of Manpower, Singapore (MOM, 2009) revealed that the accident frequency rate (AFR) and accident severity rate (ASR) are far higher than the average level among all the industries in Singapore (see Figure 1.1).

In addition, Figure 1.2 shows that accident frequency rate of all industries has experienced a continuous reduction from 1997 (the accident frequency rate was 2.6 accidents per million man-hours worked) to 2009 (the accident frequency rate was 1.8 accidents per million man-hours worked) (MOM, 2008a, 2010). There is, however, no apparent improvement in the construction safety performance. As can be seen in Figure 1.2, the accident frequency rate of construction industry has been stagnating at around 3 accidents per million man-hours worked since 1997 (Feng and Teo, 2009).



[a] Six new sectors under WSH Act11 include: Water supply, sewerage and waste management; Hotels and restaurants; Health activities; Services allied to transport of goods; Veterinary activities; Landscape care and maintenance service activities

Figure 1.1: AFR and ASR Rate in Major industries (Source: Teo and Feng, 2010)

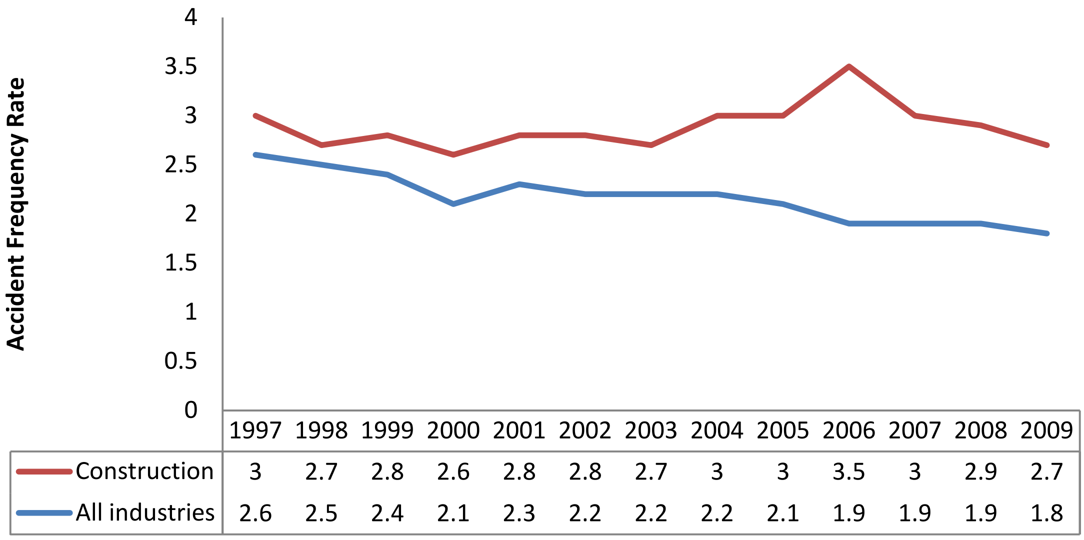


Figure1.2: Industrial Accidents by AFR (Adapted from: Feng and Teo, 2009)

Fatalities and severe injuries continue to happen at construction sites in recent years. The collapse of Nicoll Highway along with two other major accidents in 2004, which claimed a total of 13 lives, is a stern reminder that more needs to be done to protect workers (MOM, 2007a). Such high frequency and severity rates had prompted the government, industries, and researchers to examine various strategies for enhancing construction site safety performance.

1.2 Statement of the problem

In 2005, the government undertook a fundamental reform in the WSH framework in order to achieve a quantum improvement in the safety and health for workers. The target was set to halve the current occupational fatality rate within 10 years (from 4.9 fatalities per 100,000 workers in 2004 to 2.5 in 2015) and attain standards of the current top ten developed countries with good safety records (MOM, 2007b). The new framework is guided by three principles (see Table 1.1). It is designed to engender a paradigm shift in mindset where the focus is on reducing the risks and not just complying with prescriptive rules (MOM, 2007b). Industry will be required to take greater ownership of safety outcomes. Businesses should realize that good WSH performance will enhance business competitiveness, for example, good corporate image, cost savings in terms of higher productivity and fewer disruptions to work due to accidents. It is suggested that the potential benefits of good WSH performance may motivate businesses to voluntarily invest in WSH loss control activities, instead of just complying with rules and regulations.

Table 1.1: Principles of the New WSH Framework

Three Principles	**Desired Mindset Change**	
	From	**To**
Reduce risk at source by requiring all stakeholders to eliminate or minimize the risks they create	Managing risks	Identifying and eliminating risks before they are created
Greater industry ownership of WSH outcomes	Compliance with "Letter of the law"	Proactive planning to achieve a safe workplace
Prevent accidents through higher penalties for poor safety management	Accidents are costly	Poor safety management is costlier

(Source: MOM, 2007b)

The reform in the WSH framework suggests that if the prescriptive rules and enforcement procedures do not produce desired results, attention should be directed toward a self-regulating or self-motivating solution to this problem. The Robens Report, Safety and Health at Work (1972) takes the view that too much law encourages apathy and apathy is what causes accidents at work. Therefore, voluntary, self-generating effort seems to be an important way to reduce accidents in industry (Nichols, 1997).

To many people, the main objective of a business is to make profit, which is also used as a criterion of success (Appleby, 1994). Thus, one way in which such a self-generating solution could occur would be if decision makers of a business had in-depth understanding of the financial cost and its implications of WSH issues. The main driving force behind the industrial safety movement is the fact that accidents are expensive, and substantial savings can be made by preventing them (U.S. Department of labor, 1955). Many modern managers treat preventing accidents as an investment – an investment with significant returns, both humane and economic (Bird and Germain, 1996). Brody *et al.* (1990) pointed out that when prevention activities are perceived as sufficiently profitable, the investor will likely undertake the investments voluntarily.

However, as the investments in workplace safety cannot be limitless, the problem is that it is not known how much money should be invested in improving workplace safety performance. There is, therefore, a need for a scientific way to support the decision making about the amount to be invested for workplace safety. The present study was proposed to address this need by investigating the desirable level of safety investments for building projects.

The subsequent section provides a brief overview of the effect of safety investments on safety performance and the optimum safety costs and investments, and then identifies the knowledge gap. A more detailed review of literature is presented in Chapter two.

1.3 Knowledge gap

1.3.1 Effect of safety investments on safety performance

Safety investments are defined as the costs which are incurred as a result of an emphasis being placed on safety control, whether it is in the form of safety training, safety incentives, staffing for safety, Personal Protective Equipment (PPE), safety programs, or other activities (Hinze, 1997). A detailed review of safety investments is provided in Section 2.3.1.

A popular assumption holds that the higher the safety investment is, the better the safety performance will be (Levitt, 1975; Laufer, 1987b; Brody *et al.*, 1990; Hinze, 2000); nevertheless, little empirical evidence was found to support this assumption. Crites (1995) compared safety performance with the size and funding of formal safety programs over an 11-year period (1980-1990). However, it was found that safety performance was independent of – or even inversely related to – safety investment.

Tang *et al.* (1997) examined the function of the relationship between safety investment and safety performance of building projects in Hong Kong and found a weak correlation coefficient (0.25) between safety investment and safety performance. They assumed that the low coefficient of correlation (0.25) might be due to the difference in safety culture of the different companies. However, no empirical evidence was provided to support this assumption.

Crites (1995) and Tang *et al.* (1997) provided empirical evidence for the relationship between safety investments and safety performance; nevertheless, they failed to identify the factors influencing this relationship. The reasons for why safety performance is weakly or even inversely related to safety performance remain unclear.

The accident causation theories, risk compensation theory and risk homeostasis theory suggest that safety performance is likely the result of the interactions of safety investments, safety culture and project hazard (please refer to Section 3.2 for a detailed discussion). The effect of any factor on safety performance may vary with changes in the other two factors. However, it appears that so far no studies have been conducted to investigate the interactive effects of safety investments, safety culture and project hazard on safety performance. It is still unclear whether the relationship between safety investments and safety performance is affected by other factors, such as initial hazard level and safety culture level of the project.

1.3.2 Optimization of safety investments

The concept of optimum safety investments states that a company would invest a certain amount of dollars in safety which will coincide with the minimal point of total safety costs (Diehl and Ayoub, 1980; Hinze, 2000). Theoretical/hypothetical analyses (Brody *et al.,* 1990; HSE, 1993b; Laufer, 1987) and empirical investigations (Tang *et al.,* 1997) have been conducted to apply the concept of optimum safety investments to workplace safety management. A detailed review of these studies is provided in Section 2.5.3.

HSE (1993b) suggested that it is possible to identify a level of OHS risk that represents the optimum economic level of safety investments and accident costs. This risk level coincides with the point at which the cost benefits of safety interventions are just equal to the additional costs incurred (HSE, 1993b). Laufer (1987a, b) demonstrated the application of the concept of optimum safety investments through the hypothetical changes in the method of determining insurance premiums in Israel and in management's perception of accident prevention costs. Brody *et al.* (1990) applied the concept of optimum safety investments to demonstrate the importance of indirect accident costs. However, these studies were carried out based on the hypothetical relationships among safety investments, accidents cost, and safety performance. As these studies were without the support of empirical evidence, there is a need for empirical examinations on optimum safety investments. This need was addressed by Tang *et al.* (1997) in their empirical research on safety cost optimization of building projects in Hong Kong.

Tang *et al.*'s (1997) empirical study adds valuable insight into the relationship among safety investments, accident costs, total safety costs, and safety performance. Functions and curves for the relationships among these factors were developed. Although it quantified the minimal level of safety investments required for building projects in Hong Kong, some limitations of this study seem to be prominent.

Firstly, much of the analysis in their research was based on speculation and assumption. For example, the exponential relationship between safety costs/investments and safety performance seems to be a "rule of thumb" relationship instead of any theoretically derived relationship. Thus, Tang *et al.*'s (1997) study lacked rigorous mathematical analysis on the relationships between safety investments, accident costs and safety performance.

Secondly, the optimal safety investments formula (presented as the percentage of contract sum) found by Tang *et al.* (1997) is a coarse measure because the formula is universal for any type of building project regardless of the characteristics of an individual project. The formula also cannot be tailored for an individual project, whereas studies have shown that the initial project hazard level and project/contractor safety culture level do have impacts on the safety performance. The functions describing the relationship among safety investments, overall safety costs, accident costs and safety performance obtained by Tang *et al.* (1997) failed to show the influences of project hazard level and safety culture level.

In summary, previous studies failed to: (1) identify the factors influencing the relationship between safety performance and safety investments; (2) explain why safety performance was weakly or even inversely related to safety investments; (3) address the possible interactive effects of safety investments, safety culture and project hazard on safety performance; (4) develop rigorous mathematical models on the relationships among safety investments, accident costs, and safety performance; and (5) integrate the impacts of project hazard level and safety culture level in the optimization of safety investments.

Therefore, the gaps in knowledge are: (1) it is not known what factors influence the relationship between safety performance and safety investments; (2) there is no systematic model addressing the possible interactions of safety investments, safety culture, and project hazard; and (3) there is no rigorous safety investments optimization model with integration of project-specific factors, such as safety culture level and project hazard level. These aspects would be addressed in this study.

1.4 Research objectives

The purpose of this study is to investigate the financially optimum level of investments in workplace safety by exploring the relationships between safety investments, safety performance and accident costs for building projects in Singapore. The specific objectives of this research are given below.

Objective 1 - To examine the effects of safety investments on safety performance of building projects.

Objective 2 – To develop a model for determining safety performance of building projects.

Objective 3 – To investigate the costs of accidents for building projects.

Objective 4 – To study the financially optimal level of safety investments for building projects.

1.5 Significance of study

This study may provide the basis for financial decision making to manage construction safety for building contractors. Such knowledge should be of interest to building contractors as they may use it to effectively allocate resources to various activities within the fixed project budget and to better control the costs of the whole project. Understanding the principle of optimal safety investments, project decision makers would regard reasonable investments in workplace safety as a profitable activity, and then would be more ready to integrate the investments in workplace safety as a part of the whole business planning. On the other hand, this study may offer a better understanding of the theory behind:

- the effects of the interactions between safety investments, project hazard level and safety culture level on safety performance, and
- the decision making mechanism on the desirable level of safety investments of building projects.

1.6 Unit of analysis and scope of research

Since safety costs vary with regions, industries, and level of organisations (project or company level), this study was conducted at the project level in the context of building construction in Singapore. This is because: (1) building construction is the most significant segment of Singapore’s construction industry as the demand for buildings is around 70% of the total construction demand (BCA, 2006); and (2) time and resource constraints impede the development of a universal model to cater for all types of construction projects.

The research problem and objectives of this study suggest a project level of analysis. The unit of analysis in this study is a contractor’s project. Safety investments and accident costs are confined to those incurred by the project (including those relevant overhead costs allocated to the project) from the perspective of contractors (including main contractors and subcontractors). Consultant and client project organisations were not targeted in the research design. Those costs and investments incurred by the other parties of building projects (e.g. the consultants and clients) are not included in this study. For the contractor’s project in this context, typical members include: project manager/director, site manager, site engineer, site quantity surveyor, planning engineer, safety manager, safety officer, safety supervisor, foreman, etc.

In this study, the costs of workplace accident are confined to the financial losses of contractors (including main contractors and subcontractors) which are allocated to the project. Unlike the financial costs of accidents, social costs are those ‘*costs incurred by the society because additional resources are required to be utilized when construction accidents occur, and if there were no accidents, the utilization of these society’s resources could have been saved*’ (Tang *et al.*, 2004; Saram and Tang, 2004, p. 645-646). The social costs and non-material losses due to pain, suffering and loss of enjoyment of life undergone by the victim are not included in this research because they do not reflect the losses born by the contractors. The intangible costs of accidents (e.g., damage to company reputation and morale of employees) were also excluded from this study because this study concentrated only on financial aspects of accidents due to the constraints of time and resources.

Researchers have grouped the root causes of accidents on construction sites into four categories: management failure, unsafe acts of workers, non-human-related events and an unsafe working condition (refer to Section 2.2). However, the impacts of non-human-related-factors like inclement weather, unexpected ground conditions and natural disasters on safety performance of building projects are not within the scope of this research.

1.7 Definition of terms

1.7.1 “Accident(s)” versus “injuries”

The terms “accidents” and “injuries” often are mistakenly used interchangeably. Actually, the meanings are different, and the differences are important for statistical accuracy and the orienting of safety management objectives (Grimaldi and Simonds, 1975). In the “Workplace Safety and Health (Incident Reporting) Regulations 2006” of Singapore (MOM, 2006), an accident is defined as any unintended event which causes bodily injury to a person and a workplace accident is any accident occurring in the course of a person’s work, with the following exceptions: (1) any accident that occurs while a person is commuting to and from the workplace; (2) any traffic accident on a public road; and (3) any accident that occurs in the course of a domestic worker's employment. Thus, one accident may involve several injuries. Since this study is conducted in the context of building construction in Singapore, this definition of accident is adopted throughout this study. Therefore, according to this definition, the numbers of “accidents” and “injuries” experienced by a given organisation for a period of time are unlikely to be equal.

1.7.2 Financial costs of accidents

Losses could be incurred by private individuals, firms and society due to the occurrence of construction work injuries. Financial costs of work injuries represent the losses incurred by the private investors, such as contractors, due to the occurrence of construction accidents (Tang *et al.*, 2004). Losses incurred by society, such as human suffering and impact on family and society, are referred to as social costs of work injuries (Tang *et al.*, 2004). Social costs of work injuries will result in the utilization of national resources, while financial costs of work injuries will only result in the utilization of resources of private investors. In this study, financial costs of accidents refer to the financial losses born by firms as a result of accidents.

1.7.3 Safety investments

Safety control activities represent those practices implemented by private investors, such as contractors, aimed at reducing the risk or preventing the occurrence of accidents which result in the injuries of workers (Hinze, 2000). The investments in safety control activities are then defined as the costs which are incurred as a result of an emphasis being placed on safety control, whether it be in the form of safety training, safety incentives, staffing for safety, Personal Protective Equipment (PPE), safety programs, or other activities (Hinze, 2000). In this study, the terms "*investments in safety control activities*", "*investments in workplace safety*" and "*safety investments*" are used interchangeably.

1.8 Organisation of the thesis

The thesis is organized into eight chapters. Chapter 1 introduces the background, research problems, knowledge gap, research objectives, significance and scope of this study. Chapter 2 reviews the previous studies based on the research problems and the objectives of this study. Chapter 3 presents the theoretical basis of this study and develops the theoretical framework for this study. Chapter 4 presents the methodology of this study. Chapters 5 analyses the data collected. Chapter 6 discusses the statistical results within the context of theories. The last chapter presents the summary of main findings, the contributions and the limitations of this study, and proposes recommendations for future studies.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to review the existing body of knowledge relating to factors determining safety performance and economic aspects of construction safety. Section 2.2 reviews the theories of accident causation. Section 2.3 identifies the factors influencing safety performance based on the accident causation theories and reviews the measurement of the factors. Section 2.4 reviews the theories of accident costs and provides some background information about the measurement of accidents costs. Then, factors influencing the size of direct and indirect accident costs as well as the ratios between them are identified. In section 2.5, previous studies on the economic evaluation of safety investments and theories about safety costs/investments optimization are reviewed.

2.2 Accident causation theory

Heinrich *et al.* (1980) defined an accident as an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof. Accident prevention activities are likely to be shaped by causes of accidents (Lingard and Rowlinson, 2005). Many researchers have tried to understand occupational accidents by introducing accident causation models.

The research in accident causation theory was pioneered by Heinrich (1931), who analyzed 75,000 accidents reports and developed the domino theory (model) of accident causation. There are five dominoes in this model: ancestry and social environment, fault of person, unsafe act and/or mechanical or physical hazard, accidents, and injury. Heinrich (1931) suggested that this theory was likened to dominoes falling, i.e., if one condition occurred, it would cause the next and so on. Heinrich’s (1931) analysis also led him to conclude that 88 per cent of accidents were caused by unsafe acts, and only 10 per cent were caused by unsafe conditions. Peterson (1982) summarized Heinrich’s accident causation theory (1931) into two main points: (1) people are the fundamental reason behind accidents; and (2) management is responsible for the prevention of accidents. This suggests that accidents could be somewhat prevented through endeavours of management.

Heinrich’s (1931) theory was criticized for focusing too much on the immediate causes of accidents. Many researchers have updated Heinrich’s domino model with an emphasis on management as a primary cause in accidents, e.g., the updated domino sequence (Bird, 1974; Bird and Loftus, 1976), the Adams updated sequence (Adams, 1976) and the Weaver updated dominoes (Weaver, 1971). These upgraded domino models traced the occurrence of accidents back to lack of management control. The updated domino models suggest that management failure is the root cause of accidents and that the long-term solutions must focus on the first domino in the sequence, management control.

The multiple causation models, which are management based instead of domino based, hold that many contributing factors, causes and sub-causes combine together in a random manner causing an accident (Petersen, 1971). Petersen (1971) argued that these factors need to be addressed in accident investigation so that the surrounding factors to the accident could be revealed. Petersen (1971) believes that unsafe acts or unsafe conditions may be the proximate causes rather than the root causes of an accident. Thus, trying to find out the unsafe acts or unsafe behaviours is dealing only at the symptomatic level (Abdelhamid and Everett, 2000). Hopkins (1995) suggests that it is misguided to attribute accidents to either and unsafe acts or an unsafe condition because most accidents are the result of a complex interaction of multiple causes.

DeReamer (1980) has grouped the causes of accidents into two categories: immediate causes of accidents and contributing causes of accidents. The former includes unsafe acts and unsafe conditions, while the latter includes mental and physical conditions of the workers and the management policies. In construction industry, Abdelhamid and Everett (2000) have grouped the root causes of accidents on construction sites into four categories: (1) management actions/inactions; (2) unsafe acts of workers; (3) an unsafe working condition that is a natural part of the initial construction site conditions; and (4) non-human-related events. For example, management may fail to provide adequate personal protective equipments; fail to maintain or safeguard tools and equipment; fail to provide proper supervision; fail to regularly check work progress, tools, equipments and temporary structures; and violate workplace standards by allowing slippery floors, insufficient ventilation, poor housekeeping; etc. A worker may commit unsafe acts regardless of the initial conditions of the work. Example of worker unsafe acts include the decision to proceed with work in unsafe conditions, lack of skill and training, disregarding standard safety procedures such as not wearing safety helmet or safety glasses, working with insufficient sleep, sabotaging equipment, etc. Unsafe working condition is a condition in which the physical layout of the workplace or work location, the status of tools, equipment, and material are in violation of contemporary safety standards. Examples of such unsafe working conditions include open-sided floors, defective ladders, improperly constructed scaffolds, defective tools/equipments, uneven terrain, concealed ditches, etc. The last category of root causes is non-human-related events, such as earthquakes, storms, unexpected ground conditions/terrain, etc (Abdelhamid and Everett, 2000).

Fang *et al.* (2004) divided hazard factors into two categories: (1) factors outside the construction site, such as the safety involvement of the employer, designer, subcontractor, consultant, insurer and the public demand and concern on occupational health and safety; and (2) on-site hazards, including the physical conditions and all on-site activities of managers, workers and other organisations, which are then grouped into two categories: immediate factors and contributing factors (see Figure

2.1). An immediate hazard factor is a factor that can cause an accident physically and directly, whether the accident happens or not, including unsafe acts and unsafe conditions. A contributing hazard factor is a factor that can further explain immediate hazard factor, including safety management policy, manager and worker's mental or physical conditions, initial construction site conditions, and so on.

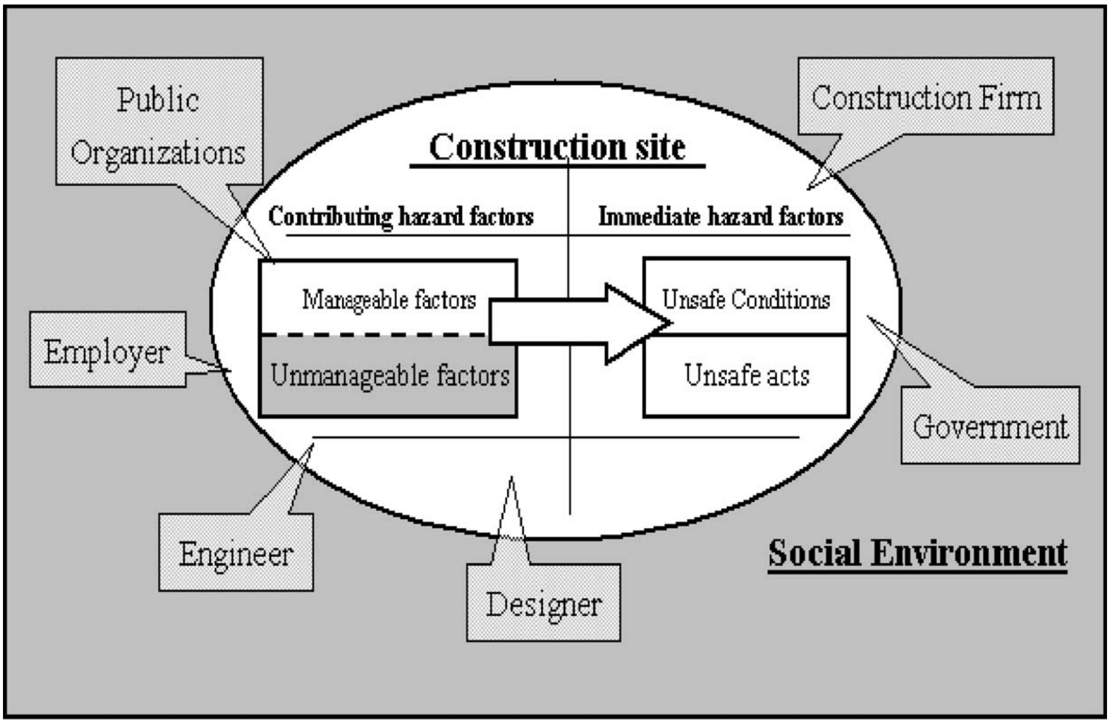


Figure 2.1 Hazard Factors on Construction Site (Source: Fang et al., 2004)

2.3 Factors influencing safety performance of building projects

Efforts to prevent accidents are likely to be shaped by the root causes of accidents (Lingard and Rowlinson, 2005). The accident causation theories suggest that lack of management control is the root cause of accidents and thus the accidents could be somewhat prevented through management efforts. The *Oxford English Dictionary* (OED, 2012) defines the control as the ability or power to determine or influence people’s behaviour or the course of events. Langer (1975) noted that ‘*In skill situations there is a causal link between behaviour and outcome. Thus, success in skill tasks is controllable. Luck, on the other hand, is a fortuitous happening. Success in luck or chance activities is apparently uncontrollable*’ (as cited in Kahneman *et al.*, 1982, p.231). However, due to people’s strong desire to completely master their environment and control chance events (Adler, 1930; Hendrick, 1943; White, 1959; DeCharms, 1968) and the fact that skill and chance factors are so closely associated in people’s experience, Langer (1975) found that there is ‘*an expectancy of a personal success probability inappropriately higher than the objective probability would warrant*’ (as cited in Kahneman *et al.*, 1982, p.232), which is referred to as the illusion of control. Langer’s (1975) research suggests that the lack of management control cannot account for all the failures in managing WSH risks due to the role of chance factors. Therefore, in addition to the level of management efforts in accidents prevention, safety performance of building projects is also associated with the inherent project hazards and non-human related events, such as natural disasters and inclement weather (Abdelhamid and Everett, 2000; Imriyas *et al.*, 2007b; Teo and Feng, 2010, 2011). The management efforts could be in the form of physical input such as the investments in safety personnel, safety facilities and equipments, safety training, and other safety related activities, and cultural input such as the cultivation of safety culture in construction sites (Feng, 2009; Teo and Feng 2011). The inherent project hazard is a natural part of the initial construction site conditions owing to the scope and location of the project (Abdelhamid and Everett, 2000; Imriyas *et al.*, 2007b). Non-human related events like natural disasters and inclement weather are beyond control and prediction (Teo and Feng, 2010). The subsequent sections review the literature about the definitions and measurement of safety investments, safety culture, and inherent project hazards.

2.3.1 Safety investments (Physical input)

2.3.1.1 Concept of safety investments

Safety investments are cost paid for pursuing people’s health, the security of life, and living safeguard (Hinze, 2000). It is aimed at protecting the health and physical integrity of workers and the material assets of a contractor (Tang *et al.*, 1997). Safety investments were also referred to as the costs of safety by Hinze (2000), who presented that the costs of safety are those which are incurred as a result of an emphasis being placed on safety, whether it be in the form of training, drug testing, safety incentives, staffing for safety, personal protection equipment, safety programs, etc. According to Hinze (2000), investments in safety must be viewed as a means to improve the bottom line, and naturally, to reduce the incidence of injuries, rather than just an operational cost.

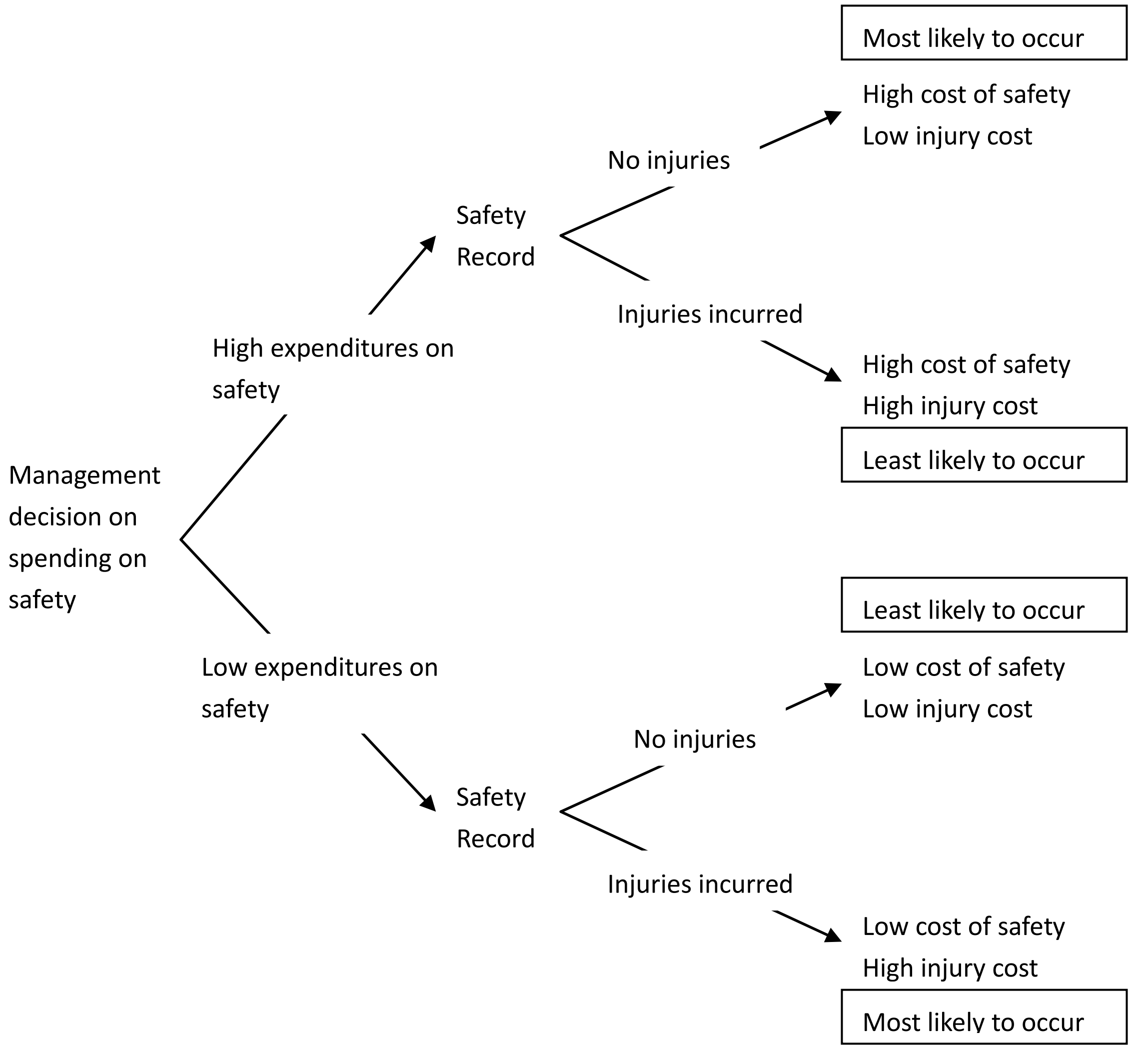


Figure 2.2: Emphasis on Safety and Injury Occurrence (Source: Hinze, 2000)

Safety investments are always believed to have a positive impact on safety performance of building projects (e.g., Levitt, 1975; Laufer, 1987a, b; Brody *et al.*, 1990; Tang *et al.*, 1997). However, this impact is largely an issue of probabilities, as there might be no injuries even if there is no investment in safety. The decision tree developed by Hinze (2000) may best illustrate the issue of probabilities (see Figure 2.2). It shows the various possible outcomes related to emphasizing safety and incurring injuries. If the investments in safety are high, the probability of incurring high injury cost becomes relatively small. On the other hand, if the investments in safety are low, the chance of sustaining high injury cost can be relatively high.

However, much of the analysis in these studies was based on assumptions. Little empirical evidence was found to support their arguments. Crites (1995) compared safety performance with the size and funding of formal safety programs over an 11-year period (1980-1990), and it was found that safety performance was independent of – or even inversely related to – safety investment. Tang *et al.* (1997) examined the function of the relationship between safety investment and safety performance of building projects in Hong Kong and found a weak correlation coefficient (0.25) between safety investment and safety performance. They assumed that the low correlation coefficient might be due to the difference in safety culture of the different companies without the support of empirical evidence. These studies failed to address the possible interactions of safety investments and other factors influencing safety performance. From these studies, it is still unclear whether the relationship between safety investments and safety performance is affected by other factors, such as initial hazard level and safety culture level of the project.

2.3.1.2 Components of safety investments

The components of safety investments have been discussed in some previous studies (e.g., Laufer, 1987a, b; Brody *et al.*, 1990; Tang *et al.*, 1997; Hinze, 2000). Accident prevention comprises expenses for safety planning, acquisition of equipment and protective installations, personnel training, salaries for safety staff, safety measurement and accident investigations (Laufer, 1987a, b). Brody *et al.* (1990) classified safety investments into three types: (1) Fixed prevention costs (FPC); (2) Variable prevention costs (VPC); and (3) Unexpected prevention costs (UPC). FPCs are incurred before production takes place and exist regardless of the accident rate. Examples of FPCs include human resources allocated to safety. VPCs are proportional to accident frequency and severity. They include time taken by accident analysis specialists attempting to identify causes and to prescribe corrective measures. UPCs relate to measures initially unforeseen when a production procedure is originally conceived or when machinery is designed or purchased.

In an attempt to optimize construction safety cost, Tang *et al.* (1997) collected the data on the investments in safety of building projects in Hong Kong. The information on safety investments was divided into three major investments components, namely (1) safety administration personnel, (2) safety equipment, and (3) safety training and promotion. Investments in safety administration personnel comprise the salaries of these personnel, such as safety officers, safety supervisors, or safety managers in some large companies, and their supporting staff such as clerks and typists. Investments in safety equipments include the expenditures on personal protection equipments and other equipments that involve the provision of safety on building sites. Expenditures on safety training and promotion are also part of safety investments.

Hinze (2000) discussed the most salient components of a safety program. Various experts (primarily associated with the petro-chemical and industrial sectors) in industry were consulted about the costs of the various components of a safety program. These safety program elements include: (1) substance abuse testing; (2) staffing; (3) training; (4) personal protective equipment; (5) safety committees; (6) investigations; (7) preparation and implementation of safety program; and (8) safety incentives.

2.3.2 Safety culture (Cultural input)

2.3.2.1 Organisational culture and climate

- Concepts of organisational culture

The American Heritage Dictionary defines culture as ‘*the totality of socially transmitted behaviour patterns, arts, beliefs, institutions, and all other products of human work and thought considered as the expression of a particular period, class, community, or population’*. Since the early 1980s, culture studies have acquired the dominant status in the management academia (Hofstede, 1991; Cameron and Ettington, 1998; Brown, 1998; Collins, 2000; Martin, 2002). The concept of organisational culture had its roots in several disciplines including psychology, sociology, anthropology and management. These diverse perspectives resulted in numerous and conflicting approaches to define organisational culture (Cooper, 2000; Schein, 1990, 1992).

Organisational culture was defined as: a pattern of beliefs and expectations shared by the organisation's member (Schwartz and Davis, 1981); the way we do things around here (Deal and Kennedy, 1982); a general constellation of beliefs, norms, customs, value systems, behavioural norms, and ways of doing business (Tunstall, 1983); a set of commonly held attitudes, values, assumptions, beliefs that guide the behaviour of an organisation's members (Martin, 1985); commonly held and relatively stable beliefs, attitudes and values that exist within the organisation (Williams *et al.*, 1993); the collective mental programming of the mind that distinguishes the members of one organisation from another (Hofstede, 1991); etc.

Schein (1992, p.8-9) provides a useful summary of the way the concept of culture has been used by various researchers: observed behavioural regularities, group norms, espoused values, formal philosophy, rules of the game, climate, embedded skills, habits of thinking, shared meanings and root metaphors. Cooper (2000) attributed the difference between various definitions of organisational culture to '*their focus on the way people think, or on the way people behave*' (p.112). Moreover, after discussing whether it is better to focus on values or practices in defining organisational culture, Hofstede (1991) stated that '*shared perceptions of daily practices should be considered to be the core of an organisation's culture'* (p. 182-183). Despite the distinction of different definitions of organisational culture in terms of their focus on values or practices, Hopkins (2006) stressed that they are not necessarily in conflict with each other, as '*a definition in terms of practices does not deny the importance of values in any complete understanding of culture'* (p.876).

- Dimensions of organisational culture

A number of attempts have been made to map the main features or levels of organisational culture. Hofstede (1991; 2001) discusses organisational culture primarily in relation to national culture. The Hofstede dimensional model of national culture (Hofstede, 2001) distinguishes national cultures according to five dimensions: power distance; individualism/collectivism; masculinity/femininity; uncertainty avoidance; and long-/short-term orientation. He conceives culture as having multiple layers: norms and values (core layer), rituals, heroes and symbols (outer layer). At each of these levels, culture has its manifestations which can be studied separately. According to Hofstede (1991), only the last three layers are relevant in considering organisations. He refers to the last three layers as ‘practices’ in contrast the core layer –norms and values. The practices are more easily changed than the norm and values, while the more outward a layer is situated, the more superficial it is.

Schein (1992) depicts organisational culture into three different levels: Artifacts, espoused values, and basic underlying assumptions. At the deepest level are the taken-for-granted assumptions about the organisation from which values are formed and actions are derived. They serve as a mental map for members to guide their behaviours and to shape their way of seeing, thinking, and feeling about what is happening around them. At the intermediate level are organisational members’ espoused values and ideals (i.e. how they think and feel) that shape their behaviours. The most accessible level (the surface level) refers to physical manifestations and overt routine behaviours grounded in values and assumptions. These are the artifacts and products of a culture that we can see, hear and feel (Cai, 2005). Hofstede, as the pioneer in the culture studies, identified six mutually independent dimensions of organisational culture using factor analysis (Hofstede, 1991). These dimensions are: process oriented vs results oriented; employee oriented vs job oriented; parochial vs professional; open system vs closed system; loose control vs tight control and normative vs pragmatic.

Other key dimensions of organisational culture identified include depth, breadth and progression (Eldridge and Crombie, 1974). Depth refers to the way in which culture is reflected the organisation’s policies, procedures, processes, programs, values, strategies, behaviours and other features. Breadth is represented in the lateral coordination of different organisational components. Progression refers to the time dimension, and is similar to the developmental aspect of culture espoused by Schein (1992). Gorman (1989) identified three further dimensions: strength, pervasiveness and direction. Strength is the extent to which organisation members embrace core level meanings. Pervasiveness refers to the extent to which beliefs and value are shared across the organisation. Direction refers to the extent to which organisational culture embodies behaviour that is consistent with espoused strategy. Jaeger (1986) used a set of four dimensions namely power distance, uncertainty avoidance, individualism and masculinity, which were originally developed by Hofstede (1980) for defining national cultures. Rousseau (1990) used a two-dimension of organisational culture in a survey of a large service organisation: satisfaction-orientation and security-orientation. Marcoulides and Heck (1993) used five dimensions to depict organisational culture: organisational structure, organisational values, task organisation, organisational climate and employee attitudes. Ashkanasy, Broadfoot and Falkus (2000) developed ten dimensions of organisational culture, which comprise leadership, structure, innovation, job performance, planning, communication, environment, humanistic workplace, development of individual and socialization on entry.

- Organisational culture and organisational climate

Various researchers have attempted to distinguish the concept of organisational culture from the concept of organisational climate, which have been used interchangeably. Glendon and Stanton (2000, p.198) argued that ‘while there is a relationship and some overlap between these terms, organisational climate refers to the perceived quality of an organisation’s internal environment’. Hofstede (1986) narrows organisational climate down to job satisfaction and to something that is typically the concern of lower and middle management. Hofstede (1986) regards organisational culture as top-management’s business. Rousseau (1988) reviewed 13 definitions of organisational climate over a 21-year period, in which employee attitudes and perceptions were identified as the main features of organisational climate. Furnham and Gunter (1993) regard organisational climate as an index of organisational health, but not a causative factor in it. Mearns *et al.* (2003) refers to climate as a manifestation of culture. They argue that climate is directly measurable while culture is too abstract to be measured directly. Hale (2000) defines climate as the situation at a particular point in time while culture refers to more enduring phenomena.

Through a comprehensive review of organisational culture theory and research, Guldenmund (2000, p.221) concludes that '*the term organisational climate was coined to refer to a global, integrating concept underlying most organisational events and processes'*. Guldenmund (2000) suggests that the difference between climate and culture may be little more than terminological fashion. Nowadays, 'the term organisational climate has come to mean more and more the overt manifestation of culture within an organisation' (Guldenmund, 2000, p.221). It is also observed that the terms climate and culture originated from different academic disciplines, namely social psychology and anthropology, respectively (Hopkins 2006). Climate and culture tend to be associated with the different research strategies: quantitative approach and qualitative approach, respectively. Therefore, Hopkins (2006, p.877) suggests that '*while the distinction between culture and climate remains elusive, what is clear is that there are real choices to be made in terms of research strategy*'.

2.3.2.2 From organisational culture to safety culture

- Concepts of safety culture

Contrasting perspectives on organisational culture can be used as a framework for appreciating how values, attitudes and beliefs about safety work are expressed and how they might influence directions that organisations take in respect of safety culture (Glendon and Stanton 2000, p. 201). The term *safety culture* was first introduced in International Safety Advisory Group's (INSAG's) *Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident* by the International Atomic Energy Agency (IAEA, 1986). The IAEA (1986), in its attempt to understand why the accident occurred, concluded that 'a poor safety culture' was one of the major reasons for the disaster. Safety culture was defined by *"Safety Culture"* (*International Safety Advisory Group, Safety-Series 75-INSAG-4)* as assembly of characteristics and attitudes in organisations and individuals, which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance (IAEA, 1991). Since then, a considerable number of definitions of safety culture have abounded in the safety literature (Choudhry, 2007; Guldenmund, 2000; Wiegmann *et al.*, 2004). According to Flin (2007), the most widely accepted definition of safety culture comes from the nuclear power industry. '*The safety culture of an organisation is the product of individual and group values, attitudes, perceptions, competencies and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety management. Organisations with a positive culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures'* (ACSNI, 1993, p.23).

A recent review of safety culture literature by Wiegmann *et al.* (2004) identified a set of critical features regardless of the particular industry from the various definitions of safety culture. These critical features include the following: '*(1) safety culture is a concept defined at the group level or higher that refers to the shared values among all the group or organisation members; (2) safety culture is concerned with formal safety issues in an organisation and closely related to, but not restricted to, the management and supervisory systems; (3) safety culture emphasizes the contribution from everyone at every level of an organisation; (4) the safety culture of an organisation has an impact on its members' behaviour at work; (5) safety culture is usually reflected in the contingency between reward systems and safety performance; (6) safety culture is reflected in an organisation's willingness to develop and learn from errors, incidents, and accidents; (7) safety culture is relatively enduring, stable, and resistant to change*' (Wiegmann *et al.* 2004, p. 123).

Notwithstanding its recent appearance in the field of safety management, safety culture has begun to gain acceptance due to its critical role for improving safety performance (e.g., Cooper, 2000; Guldenmund, 2000; Wiegmann *et al.*, 2004). As suggested by Cooper (1997), safety culture impacts not only on accident rates, but also on work methods, absenteeism, quality, productivity, commitment, loyalty and work satisfaction (Cooper, 1997). A good safety culture might be reflected and promoted by: (1) senior management commitment to safety; (2) shared care and concern for hazards and solicitude over their impacts upon people; (3) realistic and flexible norms and rules about hazards; and (4) continual reflection upon practice through monitoring, analysis, and feedback systems (Cooper, 1997; Pidgion and O'Leary, 1994).

- Models of safety culture

Many researchers have attempted to develop a theoretical model of safety culture which explains the concept of safety culture and determines how safety culture may be measured. Clarke (2000) mapped various aspects of safety culture based on Shein's (1992) three-level model of organisational culture. According to Clarke (2000), at the deepest level of safety culture model is the basic understanding that safety is the overriding priority, which is manifested as all organisational members' attitudes towards safety (the intermediate level) and as safety related organisational strategy, structures, artefacts, and practices, as well as organisational members' norm and practice (the surface level).

Guldenmund (2000) defines safety culture as those aspects of the organisational culture which will impact on attitudes and behaviours related to increasing or decreasing risk. Guldenmund (2000) also conceptualised safety culture as having three layers or levels at which it may be studied separately. The core layer is assumed to consist of basic assumptions, which are unconscious and relatively unspecific and which permeate the whole of the organisation. The next layer consists of espoused values, which are operationalised as attitudes towards the specific objects: hardware, software, people and behaviour. The outermost layer consists of particular manifestations of specific objects such as inspections, posters, wearing of personal protective equipment, accidents or incidents, near-misses or different types of behaviour.

According to Cooper (2000), '*The prevailing organisational culture is reflected in the dynamic reciprocal relationships between members' perceptions about, and attitudes towards, the operation of organisational goals; members' day-to-day goal-directed behaviour; and the presence and quality of the organisation's systems and sub-systems to support the goal-directed behaviour*' (p. 118). The reciprocal relationships between the three factors have been recognized and reflected in several major models of safety culture (Bandura, 1986; Cooper, 2000; Geller, 1994, 1996).

The model of reciprocal determinism developed by Bandura (1986) offers the framework in which the psychological, behavioural and situational elements and their interactions precisely reflect those accident causation relationships found by many researchers (e.g. Heinrich *et al.*, 1980; Reason, 1990). In order to reflect the concept of safety culture, Bandura's model was adapted by Cooper (2000), who suggested that '*organisational culture is the product of multiple goal-directed interactions between people (psychological); jobs (behavioural); and the organisation (situational)*' (p.118). In the adapted model by Cooper, the internal psychological aspects of safety culture, such as attitudes and perceptions, can be assessed by safety climate questionnaires (Zohar, 1980). The observable behavioural aspects of safety culture can be assessed through peer observations, self-report measures and/or outcome measures (Komaki, Barwick and Scott, 1978; Sulzer-Azaroff, 1987); and the objective situational aspects of safety culture, such as safety rules and procedures, can be assessed through safety management systems audits/inspections (Cooper, 1997; Teo and Ling, 2006).

Other researchers, such as Geller (1994, 1996) and Choudhry *et al.* (2007) also put forward models to reflect the concept of safety culture. The Total Safety Culture model by Geller (1994, 1996) distinguished three dynamic and interactive factors: Person, Behaviour, and Environment. The only difference between Geller’s model and Cooper’s model is that the term environment is used in the former model while the term situation is used instead in the latter model. Another model presented by Choudhry *et al.* (2007) was built upon Geller’s model and Cooper’s model and in the context of construction industry, with the distinction that the construct environment in Geller’s model and situation in Cooper’s model are incorporated into a new construct –situation/environment – to reflect not only the situational aspects of the organisation but also the specific conditions of the construction project. The reciprocal interactions among psychological, behavioural and environmental/situational variables, which have been recognized and reflected in the major safety culture models, indicate that the three dimensions to measure the overall safety culture of an organisation are psychological, behavioural and situational/environmental aspects of safety culture.

- Safety culture and safety climate

Just like the relationship of organisational culture and organisational climate, the concept of safety climate, which was mainly derived from the organisational climate theory and research, is similar and closely related to the concept of safety culture (Clarke, 2000). Some researchers used the term safety culture interchangeably with the term safety climate (Cox and Cox, 1991; Lee, 1998), while others attempted to distinguish between the two concepts (Flin *et al.*, 1998; Cox and Flin, 1998; Choudhry *et al.*, 2007). Zohar (1980) first defined safety climate as a summary of '*perceptions that employees share about their work environment*' (p. 96). Flin *et al.* (1998) defined safety climate as the perceived state of safety of a particular place at a particular time. It is therefore relatively unstable and subject to change depending on features of the operating environment. More recently, Zohar (2003) suggested, '*safety climate relates to shared perceptions with regard to safety policies, procedures and practices'* (p. 125). According to Wiegmann *et al.* (2004), although literature has not presented a generally accepted definition of safety climate, '*many definitions do have commonalities and do differ from safety culture in important ways*' (p. 124). These commonalities include: '*(1) safety climate is a psychological phenomenon that is usually defined as the perceptions of the state of safety at a particular time; (2) safety climate is closely concerned with intangible issues such as situational and environmental factors; and (3) safety climate is a temporal phenomenon, a 'snapshot' of safety culture, relatively unstable and subject to change'* (Wiegmann *et al*,. 2004, p. 124).

The aforementioned commonalities extracted from various definitions of safety culture and safety climate indicate that the two terms should not be viewed as alternatives. Safety climate tends to be the overt manifestation of safety culture within an organisation (Schein, 1990; Teo and Feng, 2009). It is also commonly accepted that safety climate provides an indicator of the underlying safety culture (Cox and Flin, 1998; Teo and Feng, 2009). This is further confirmed by Teo and Feng’s (2009) empirical research, which examined the relationship between safety climate and safety culture in construction environment and concluded that safety climate can be a reliable indicator of the overall safety culture in the construction project organisations.

- Assessing safety culture

In order to assess safety culture of an organisation, a variety of qualitative (e.g. observations, focus group discussions, historical information reviews, and case studies) and quantitative (surveys) methods can be used (Wreathall, 1995). With qualitative measurement strategies, which originate in the discipline of anthropology, organisation members usually serve as informants who interact directly or indirectly with researchers using their own terms and concepts to express their point of view (Rousseau, 1990; Wiegmannet *et al.*, 2004). Therefore, through qualitative measurement, intensive and in-depth information can be obtained using the focal group’s own language. One of the major drawbacks of the qualitative methods is the commitment of time it requires from the researcher (Hopkins, 2006).

In contrast, quantitative approaches attempt to numerically measure or score safety culture using procedures that are often highly standardized and calibrated (Wiegmannet *et al.*, 2004). In quantitative measurement strategies, organisation members usually serve as respondents who react to a standard set of questions provided by the researchers (Rousseau, 1990). The survey method appears to be the predominant strategy for studying organisational cultures (Hopkins, 2006). There are numerous safety culture and climate studies which were carried out using the survey methods (e.g. Hofstede, 1991; Cox and Cheyne, 2000; Lee and Harrison, 2000; O'Toole, 2002; Cooper and Phillips, 2004). Hopkins (2006) suggests that the survey method is not only well suitable to studying individual attitudes and values but also suitable to studying practices, or 'the way we do things around hear'. The survey methods are relatively easy to use in cross-sectional comparisons, generally simple to implement in different organisations and by other researchers, and straightforward to interpret according to a common, articulated frame of reference (Wreathall, 1995; Wiegmannet *et al.*, 2004). The limitations of the survey methods are: (1) it provides a relatively superficial description of the culture of an organisation; and (2) it provides little information about dynamic processes of organisational culture.

There appears to be agreement among researchers that both qualitative and quantitative methods have unique contributions for assessment and theory testing (Wiegmannet *et al.*, 2004). Nonetheless, quantitative approaches, especially surveys of individuals' responses, are often more practical in terms of time and cost-effectiveness (Wreathall, 1995; Wiegmannet *et al.*, 2004). Consequently, surveys and questionnaires have been widely used to assess safety culture within a variety of industries such as nuclear power, chemical, construction, transportation, and manufacturing (Cox and Cheyne, 2000; Lee and Harrison, 2000; O'Toole, 2002; Cooper and Phillips, 2004; Molenaar *et al.*, 2009).

2.3.3 Project hazard

According to Imriyas *et al.* (2007b), the project hazard is a natural part of the initial construction site conditions owing to the scope and location of the project. Higher project hazard level tends to be associated with higher risk level on site (Imriyas *et al.*, 2007b). To assess the project hazard level, researchers (Davies and Tomasin, 1996; Jannadi and Assaf, 1998) introduced a list of high hazard activities in building projects, which are discussed as following.

2.3.3.1 Demolition hazards

Demolition is one of the high-risk activities of the construction industry. According to King and Hudson (1985), demolition workers face a variety of hazards: (1) Falling from heights; (2) Being hit or trapped by falling objects; (3) Excessive noise from hand-held tools, demolition balls, pneumatic drills, explosives and falling parts; (4) Vibration from hand-held pneumatic tools; (5) Respiratory hazards from dust which may contain toxic constituents such as asbestos and silica; (6) Flying particles causing eye and skin injuries; and (7) Fires and explosives, especially when demolishing tanks that contained oils or flammable chemicals. Davies and Tomasin (1996) noted that the risk in demolition works is influenced by four variables, namely volume/size of demolition, type of structure, method of demolition and level of site supervision.

2.3.3.2 Excavation work hazards

Excavations can be categorized into three common types: trenches; basements and wide excavations; and pits/shafts (for pad and pile foundations) (Davis and Tomasin, 1996). HSE (2005) summarized the ways in which accidents in excavation tend to occur. They are: (1) collapse of sides/cave-in; (2) contact with underground utilities; (3) dangerous atmospheres; (4) workers being struck by falling materials/objects from top; and (5) Workers falling into excavations. Hinze (2005) and Lee and Halpin (2003) analysed excavation-related activities and identified five hazard rating variables for excavation works: (1) excavation configuration (depth, width and length); (2) geological condition (soil type and water table); (3) presence of underground utilities (electrical, water and sewer lines); (4) nearby vehicular traffic (vibration and surcharge load); and (5) nearby structures.

2.3.3.3 Scaffolding and ladder work hazards

According to Davis and Tomasin (1996), scaffold use may potentially incur the following hazards: (1) workers falling from the working platform; (2) workers below the working platform being struck by materials falling from it; and (3) the scaffold or part of it collapsing and throwing workers off with the collapsed structure and crushing workers under it or nearby. The misuse of ladders, which provide access to scaffold or themselves are used as working platform of light works, may also cause serious accidents. For instance, ladders slip when users are climbing or working from them; users slip or miss their footing while climbing; users overbalance when carrying materials or tools; and when defective ladders are used, they fracture under the weight of the user (Davis and Tomasin, 1996). Bentley *et al.* (2006) studied the scaffolding and ladder-related accidents and reported two key risk factors: (1) design factors, such as height of the scaffold/ladder, suitability of the type for the task and height, and adequacy of design (member size, bracing, guardrails, platform size, and toe board); and (2) work environment and conditions, such as defects in the members of the scaffold/ladder, slippery condition on the platform, loading of materials and workers on the platform, and the nature of the platform the scaffold/ladder is rested on.

2.3.3.4 Falsework (temporary structures) hazards

A falsework refers to the temporary structure used to support a permanent structure during its construction and until it becomes self-supporting (Imriyas, 2007b). Falseworks may be required to support in-situ and pre-cast concrete construction, masonry arches as well as timber and steel frameworks. Imriyas (2007b) suggests that accidents in falseworks tend to occur by two ways: (1) total or partial collapse of falseworks leading to workers being thrown off or falling off from their place of work; and (2) other than the collapse of falseworks, workers slip and fall from falseworks through unprotected edges and holes of decking, and access ladders. Davis and Tomasin (1996) found that two causes may account for the collapses of falseworks in construction sites. One cause lies in the inadequacy of design. Davis and Tomasin (1996) further addresses that the deficiency in falsework design is caused by: (1) failure to correctly estimate the type and extent of loading; (2) inadequate foundation; (3) incorrect choice or use of materials; and (4) lack of provision for lateral stability. Another cause of falseworks collapses is poor assembly, which is possibly the result of the failure to inspect the materials (such as struts, planks, etc.), the soil condition at the foundation and the falsework erection.

2.3.3.5 Roof work hazards

As noted by Parsons and Pizatella (1985) and Gillen *et al.* (1997), the injuries caused by falls from roofs are typically extremely severe, requiring long periods of treatment and recovery and resulting in substantial medical costs. Hsiao and Simeonov (2001) investigated the fall-initiation factors in roofing works and categorised them under three groups: (1) design factors including height of the roof, roofing material property (e.g. slippery, brittleness, asbestos, etc.) and inclination of the roof; (2) task factors including load handling on the roof top, complexity of the task, and working environment, which causes fatigue and loss of balance; and (3) workers factors including age and safety consciousness, experience and training in roofing works, and under use/misuse of personal protective equipment.

2.3.3.6 Erection of structural framework hazards

Davies and Tomasin (1996) identified three common types of accidents that occur during he erection and assembly of structural steel or pre-cast frameworks. They are: (1) erectors falling from heights when at their places of work, going to or returning from them; (2) the collapse of the whole or part of the framework causing workers to fall or striking those at lower levels; and (3) Workers at lower levels being struck by tools or materials falling or being thrown down. Imriyas (2007b) suggests that the hazard level in erection works is dictated by the following variables: (1) height and size of the structure/erection; (2) design and erection method; and (3) provision of a safe workplace such as safe access/egress, safe working platform at heights, safe tools containers and safety equipment (safety belt, harness, net, etc.).

2.3.3.7 Crane use hazards

Davies and Tomasin (1996) identified five crane-related hazards: (1) overturning of a crane or the structural failure of its parts; (2) dropping of the suspended load; (3) electrocution; (4) trapping of people; and (5) accidents during erection and dismantling as well as loading and unloading. Researchers (Davies and Tomasin,1996; Neitzel *et al.*, 2001; Ederer, 2006) have identified a list of factors that may cause the crane failures: (1) operating on slopes; (2) instable crane foundation; (3) overloading;

(4) improper maintenance; (5) lack of communication; (6) unsafe working practice of workers; and (6) lack of supervision.

2.3.3.8 Construction machinery and tools usage hazards

The types of machinery involved in accidents include excavators and shovels, earthmoving equipment (i.e. crawler tractors and bulldozers, scrapers and graders), dumpers and dump trucks, forklift trucks, road rollers and lorries (Helander, 1991; Davies and Tomasin, 1996; Imriyas, 2007b). The types of construction tools which may incur hazards include: (1) knife; (2) hammer, sledge hammer, etc.; (3) grinding/cutting machine; (4) jackhammer; (5) drill; (6) manual saw; (7) crowbar, spit, etc.; (8) tools for screwing; (9) welding equipment – gas; (10) axe; (11) spade/excavation tools; (12) gripping, holding, pinching, pulling tools; (13) chain saw; (14) nail gun; (15) compass saw, hole saw, etc.; (16) welding equipment – electrical; (17) circular saw; (18) cutting tools; and (19) other tools (Helander, 1991).

The following types of accidents tend to be associated with the use of construction machinery and tools (Helander, 1991; Davies and Tomasin, 1996; Fredericks, *et al.*, 2002; Pontes, 2005; Imriyas, 2007b):

(1) workers being run-over or struck by machinery moving forward or reversing;
(2) collision between machinery or with fixed objects such as falseworks or scaffoldings;
(3) overturning of machinery while in operation;

(4) workers falling from machinery;

(5) eye injuries caused by foreign objects getting into eyes by operations such as grinding, welding, cutting, drilling and breaking;

(6) finger/hand injuries by cut and burns;

(7) injuries caused by moving/broken machine parts;

(8) electrocution; and

(9) vibration from powered hand-held tools, causing a group of diseases. One of them is blood circulation disturbance known as ‘vibration white finger’.

These accidents are caused by the following risk factors (Helander, 1991; Davies and Tomasin, 1996; Fredericks, *et al.*, 2002; Pontes, 2005; Imriyas, 2007b):

(1) failure of machinery, i.e. inoperative back-up alarms, brake failures, etc.;

(2) inadequate site planning resulting in poor visibility, inadequate manoeuvre space, inadequate signboards and poor site traffic control;

(3) lack of supervision and training of workers and operators;

(4) construction noise that masks the sound of back-up alarms and the sound of plant;

(5) faulty tools;

(6) unsafe handling of tools; and

(7) type of tools and duration of use.

2.3.3.9 Works on contaminated sites hazards

According to Worksafe Victoria (2005), a contaminated site may have the following substances, which are harmful to workers' health and safety: (1) metals (e.g. lead); (2) inorganic compounds (e.g. cyanide compounds); (3) oils and tars; (4) pesticides; (5) other organic compounds (e.g. benzene, toluene and polychlorinated biphenyls); (6) toxic, explosive or asphyxiate gases (e.g. methane); (7) combustible substances (e.g. petrol); (8) fibres (e.g. asbestos and synthetic mineral fibres); (9) putrescibles or infectious materials (e.g. medical/biological wastes); (10) radioactive wastes; and (11) other harmful wastes (e.g. unexploded ordinance and syringes). Worksafe Victoria (2005) further reported that short or long term health effects to people exposed to contaminants rely upon the type of contaminants on site, the quantity of contaminants present, and the duration that the workers are exposed on site.

2.3.3.10 Welding and cutting works hazards

The hazards incurred by welding and cutting works on construction sites include (Welder, arc, 2005):

(1) fire or explosion due to extreme temperatures (up to 10,000° F) from welding sparks coming into contact with flammable materials (e.g. coatings of metals, gasoline, oil, paint, thinner, wood, cardboard, paper, acetylene, hydrogen, etc.);

(2) electric shock from excess moisture (e.g. perspiration or wet conditions) and contact with metal parts which are "electrically hot";

(3) injuries due to flying sparks, particles of hot metals, molten metals, liquid chemicals, acids or caustic liquids, or chemical gases or vapours;

(4) falls during work on ladders, above ground and in confined spaces;

(5) exposure to high noise levels from welding equipment, power sources and processes;

(6) exposure to ultraviolet (UV) radiation resulting in skin burns and skin cancer. "Welder's flash" (brief exposure to UV radiation) may result in temporary swelling and fluid excretion of the eyes or temporary blindness;

(7) irritation of lungs due to heat and UV radiation; and

(8) exposure to fumes and chemical substances.

Welder , arc (2005) further reported that the level of hazard posed by welding and cutting works relies upon volume of work, location of welding and cutting, use of PPEs and housekeeping.

2.3.3.11 Confined spaces work hazards

Confined space refers to ‘a space which by design has limited openings for entry and exit, unfavourable natural ventilation that could contain or produce dangerous air contaminants, and is not intended for continuous employee occupancy’ (Imriyas, 2007b). Workers are required to enter confined spaces for tasks such as repair, inspection and maintenance, and are often exposed to multiple hazards (Imriyas, 2007b). EH&S (2006) identified the main factors that determine the level of hazards in a confined space. They include: (1) space configuration (i.e. size of the space and size of the ingress/egress); (2) purpose of the confined space (i.e. if it is currently being used); (3) activity to be involved inside the space (i.e. welding, application of solvents/adhesives, etc.); and (4) level of natural ventilation inside the space.

A particular project may have many of these activities and the level of hazard inherent in each activity is determined by its respective risk attributes (Imriyas *et al.,* 2006, 2007a, b, c). The fishbone diagram (Figure 2.3) proposed by Imriyas *et al.* (2006, 2007b) summarised the attributes that are pertinent to each hazard trade. These attributes need to be evaluated individually in the project's context for assessing project hazard level.

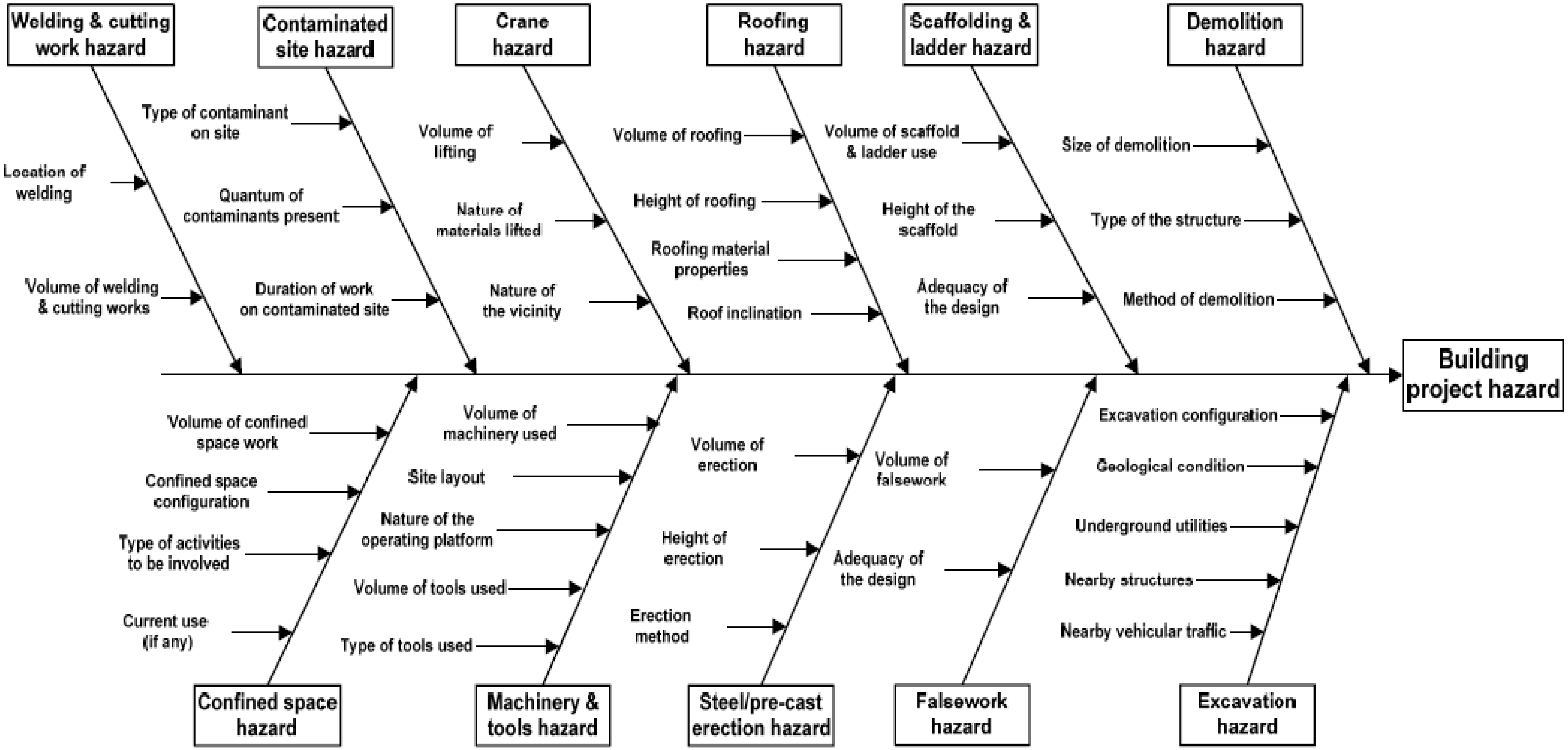


Figure 2.3: Fishbone Diagram – Building Hazard Attributes (Source: Imriyas et al., 2006, 2007b)

2.4 Accident costs

Based on the definition of accident (see Section 1.7.1), a workplace accident is any unintended event which causes bodily injury to a person in the course of a person's work. Various losses would be incurred by the injured worker(s) after the occurrence of an accident. These losses may include costs to victims and their families, to employers and to society (Davies and Teasedale, 1994). However, as stated in the scope of research (see Section 1.6), this study focused on the financial losses of an employer. Costs to victims and their families and to society were not discussed in this study.

The study on costs of accident was pioneered by Heinrich (1931) more than 80 years ago. Heinrich (1931) classified the costs as direct and indirect costs, and concluded that indirect costs are significant as he found that indirect costs accounted for as much as four times of the direct costs of accidents.

In *the Wealth of Nations* Adam Smith (1776) wrote that a man educated at the expense of much labor and time may be compared to one of those expensive machines. This view helps to shed light on the vast costs of workplace accidents. The concept of Human Capital developed by Schultz (1961), Mincer (1958) and Becker (1964) refers to the stock of skills and knowledge embodied in the ability to perform labor so as to produce economic value. The Human Capital concept indicates that the losses of skilled labour services due to injury or illness is likely to incur additional losses to employers and impact upon the competitiveness of the employers (Lingard and Rowlinson, 2005). Human Capital concept has been applied to the analysis of injuries and illnesses costs, and the Human Capital method was popularized by Rice (1967). This method also posits two broad categories of costs: direct costs and indirect costs.

Simonds and Grimaldi (1956) proposed an alternative approach by dividing the costs into insured and uninsured costs. They criticized Heinrich's (1931) definition of indirect costs, arguing that many such costs, for example the overhead cost of insurance, are direct since they appear in a firm's financial accounts. Although not all of the later researchers were persuaded to change their jargon to insured costs and uninsured costs proposed by Simonds and Grimaldi (1956), some of them were prompted to re-define the direct and indirect costs as insured and uninsured costs (Head and Harcourt, 1997).

The categorization of accident costs into direct and indirect costs or insured and uninsured costs implies that focus on the direct costs may fail to reveal the true losses to employers due to an accident. Many of the losses incurred by an accident are "hidden" and difficult to quantify. These "hidden" costs may be significant, and some may be particularly prominent in construction industry. For example, there are heavy penalties for time-overruns on construction projects (Lingard and Rowlinson, 2005). Therefore, both direct and indirect costs of accidents need to be examined to reflect the true costs of accidents to an employer. The following sections review the definitions and components of direct and indirect accident costs to employers.

2.4.1 Direct accident costs

The direct accident costs are those actual cash flows that can be directly attributable to or associated with injuries and fatalities (Everett and Frank Jr. 1996; Hinze 1997). The direct costs of injuries tend to be those associated with the treatment of the injury and any unique compensation offered to workers as a consequence of being injured (Hinze, 1997). They are typically the costs covered by work injury compensation insurance policies. In Singapore, costs covered by Work Injury Compensation Act consist of the following (MOM, 2008b):

2.4.1.1 Medical leave wages

Medical leave wages include: (a) full pay up to 14 days for outpatient medical leave; and (b) full pay up to 60 days for hospitalization leave. Beyond these two periods, 2/3 salary is payable up to a maximum period of one year following the date of accident.

2.4.1.2 Medical expenses

These include medical expenses incurred within one year from the date of accident and up to a cap of S$25,000.

2.4.1.3 Lump sum compensation

The compensation amount for permanent incapacity (PI) or death (if any) is subjected to the following limits (see Table 2.1):

Table 2.1: Compensation for Permanent Incapacity or Death in Singapore (Source: MOM, 2008b)

	Limits	Amount
Permanent Incapacity	Maximum	S$180,000 X % loss of earning capacity
	Minimum	S$60,000 X % loss of earning capacity
Death	Maximum	S$140,000
	Minimum	S$47,000

2.4.2 Indirect accidents cost

Different definitions exist for the indirect costs of accidents, but in general they are regarded as consisting of all the costs that are not covered by worker's compensation insurance (Hinze, 1991). The indirect cost theory of workplace accident developed by Brody *et al.* (1990) suggests that the identification of indirect costs will motivate cost-minimizing firms to increase investments in accident prevention to improve safety performance of building projects. The Accident Cost Iceberg proposed by Bird (1974) showed that the proportion of hidden costs could be much larger than the costs directly related to the accident.

In order to better understand the indirect accidents cost, a number of past studies have been examined. Table 2.2 lists the summary of accidents cost research undertaken since 1931. These sixteen studies give a comprehensive representation of indirect accidents cost. In addition to traditional classification of accident cost as direct (insured) and indirect (uninsured) costs, several researchers proposed different accident cost typologies based on the specific characteristics of the accident costs. For example, in the cost typology proposed by Riel and Imbeau (1996), health and safety costs are classified into three categories: insurance-related costs; work-related costs; and perturbation-related costs. They are also classified as quantifiable, irreducible and intangible costs in this typology. Rikhardsson and Impgaard (2004) argued that the traditional cost components are rather difficult for management to use, as it would require a number of definitions and clarifications before use including asset specifications and income definitions. Thus, they categorized accident costs as time, materials and components, external services and other costs. These categories reflect traditional accounting classifications in accounting systems, thus they are believed to be simpler to apply by managers. Despite the debates on various typologies of accident costs, the consequences or cost components of accidents seem to be consistent among literature.

Table 2.2: List and Summary of Previous Accident Costs Research

Reference	**Cost typology**	**Indirect to direct costs Ratio**	**Data source**	**Industrial sector**
Heinrich (1931)	***Direct costs:*** 1) Compensation 2) Medical aid ***Indirect costs:*** 1) Cost of lost time of the injured employee; 2) Cost of time lost by other employees;	4:1	U.S.	Construction; manufacturing; woodwork-ing; machine shop; and so on.

Reference	Cost typology	Indirect to direct costs Ratio	Data source	Industrial sector
	3) Cost of time lost by foremen; 4) Cost of time spent by first aid attendants; 5) Costs due to damage to machines, tools or other property; 6) Incidental costs due to interference with production; 7) Costs to employers under employee welfare systems; 8) Costs to employers in continuing the wages to the injured employee; 9) Costs due to loss of profit on the injured employee's productivity; 10) Costs that occur in consequence of weakened morale due to the accident; 11) Overhead costs per injured employee.			
Simonds and Grimaldi (1956)	***Insured costs:*** 1) Net insurance premium ***Uninsured costs:*** 1) Cost of wages paid for working time lost by workers who were not injured; 2) The net cost to repair, replace, or straighten up material or equipment that was damaged in an "accident"; 3) Cost of wages paid for working time lost by injured workers, other than workmen's compensation payments; 4) Extra cost due to overtime work necessitated by an "accident"; 5) Cost of wages paid supervisors while their time is required for activities necessitated by the injury; 6) Wage cost due to decreased output of injured worker after return to work;	No linear relationship between the two	U.S.	Manufacturing

Reference	Cost typology	Indirect to direct costs Ratio	Data source	Industrial sector
	7) Cost of learning period of new worker; 8) Uninsured medical cost borne by the company; 9) Cost of time spent by higher supervision and clerical workers on investigations or in the processing of compensation applications forms; 10) Miscellaneous unusual costs.			
Laufer (1987a)	***Insured costs:*** 1) Net insurance premium ***Uninsured costs:*** 1) Costs due to labor lost time ▪ Injured workers ▪ Other workers ▪ Replacement worker ▪ Foreman ▪ Clear-up and administration 2) Costs due to complementary wages to the injured while absent 3) Cost due to property accidents	The ratio between direct (insured) and indirect (uninsured) costs is invalid and should be abolished	Israel	Construction
Leopold and Leonard (1987)	***Insured costs*** 2) Net insurance premium ***Uninsured costs*** 1) Lost labor 2) Continuing payments to injured worker after accident 3) Insurance costs 4) Damage to equipment 5) Legal costs	1:4.5	U.K.	Construction
Klen (1989)	***Direct costs:*** 1) Accident indemnity; 2) Wages for the sick leave period minus accident insurance compensation for the same period; 3) The fee to the state for labor protection and allowance for inflation; 4) The maintenance fee of accident insurance.	1:4.7	Finland	Forestry

Reference	Cost typology	Indirect to direct costs Ratio	Data source	Industrial sector
	Indirect costs: 1) Accident investigation and report to insurance company; 2) The production loss of other workers; 3) Damage to machines and devices; 4) Disturbances in the timber harvesting chain.			
Soderqvist *et al.* (1990)	1) Lost work time for the victim, other employees, foremen, and administrative personnel; 2) Losses of current assets such as raw materials, intermediates, and finished products; 3) Losses of fixed assets such as damage to machinery, lost transport capacity, etc. 4) Outlays having shout-term effects, e.g., increased costs due to purchase of one-off services; 5) Lost revenues and other indirect costs; 6) Income from payment of indemnities on insurance policies; 7) Other consequences, such as effects on insurance premiums; 8) Utilization of health services, e.g., treatment costs, consultations, costs of health services, consumption of medicines, rehabilitation; 9) Consumption of public and private services such as transportation, job training, technical aids.	They did not investigate the ratio	Nordic (Sweden, Norway, Finland)	Furniture
Brody *et al.* (1990)	***Direct costs:*** 1) Fix insurance costs; 2) Variable insurance costs. ***Indirect costs:*** 3) Wage costs	They did not investigate the ratio	Canada	Not specified.

Reference	**Cost typology**	**Indirect to direct costs Ratio**	**Data source**	**Industrial sector**
	4) Material damage 5) Administrators' time 6) Production losses 7) Other costs 8) Intangible costs			
Hinze (1991)	***Direct costs:*** 1) Costs reimbursed by Worker's Compensation Insurance ***Indirect costs:*** 1) Cost of injured worker: 2) Cost of injured worker's crew; 3) Costs associated with obtaining medical help 4) Costs of other crews 5) Costs of equipment and material damage 6) Costs of supervisory staff 7) Other costs	4:1 for Medical cases; 20.3:1 for Restricted Activity/ Lost Workday cases.	U.S.	Construction
Rognstad (1994)	***Costs to the firm:*** 1) Time lost from work by an injured employee; 2) Lost time by co-workers and management; 3) Material damages; 4) Replacement of injured worker. ***Costs to the public sector:*** 1) Sickness pay; 2) Rehabilitation; 3) Health insurance; 4) Medical treatment; 5) Administration, police, court system; 6) Loss of tax revenue. ***Costs to the injured person:*** 1) Loss of income; 2) Expenses for medicine and medical treatment.	The study did not investigate the ratio	Norway	All industries in Norway
Everett and Frank Jr. (1996)	***Direct costs:*** 1) Benefits paid to injured workers by Workers' Compensation Insurance ***Indirect costs:***	1.65:1 ~2.54 :1	U.S.	Construction

Reference	Cost typology	Indirect to direct costs Ratio	Data source	Industrial sector
	1) WCI carriers' overhead and profit; 2) Claims costs; 3) Other costs ▪ Loss of productivity ▪ Disruption of schedules ▪ Administrative time for investigations and reports ▪ Training of replacement personnel ▪ Wages paid to the injured workers and others for time not worked ▪ Cleanup and repair ▪ Adverse publicity ▪ Equipment damage			
Riel and Imbeau (1996)	1) Insurance-related costs; 2) Work-related costs; 3) Perturbation-related costs.	They did not investigate the ratio	Canada	Manufacturing (Helicopter assembly plant)
Miller (1997)	1) Increased premiums 2) Investigation 3) Liability and property damage 4) Lost wages and benefits 5) Medical payments 6) Overheads 7) Productivity loss 8) Replacement 9) Tax payments	They did not investigate the ratio	U.S.	Highway crash
Head and Harcourt (1997)	***Direct costs:*** 1) Those paid by the Accident Rehabilitation, Compensation, and Insurance Corporation's Employers' Account ***Indirect costs:*** 1) Indirect community costs; ▪ Accident investigations by OSH ▪ Social welfare benefits 2) Indirect employer costs; ▪ Productivity losses ▪ Accident investigations	1:2.9	New Zealand	All industries

Reference	**Cost typology**	**Indirect to direct costs Ratio**	**Data source**	**Industrial sector**
	- Legal penalties - Recruitment, selection, and training 3) Indirect employee costs. - Health and medical services - Partial loss of earnings - Full loss of earnings			
Tang *et al.* (1997)	***Financial costs:*** 1) Loss due to the injured person. 2) Loss due to the injured person after resuming work 3) Loss due to medical expenses 4) Fines and legal expenses 5) Loss of time of other employees 6) Equipment or plant loss 7) Loss due to damaged material or finished work 8) Loss due to idle machinery or equipment 9) Other loss	They did not investigate the ratio	Hong Kong	Construction
Monnery (1999)	***Insured costs:*** 1) Insurance premiums ***Uninsured costs:*** 1) Cost of absentees time 2) Cost of other person's time 3) Travel to hospital 4) Replacement labour 5) Machine breakdown 6) Opportunity costs (Financial costs)	3.3:1	U.K.	Financial services sector
Rikhardsson and Impgaard (2004)	1) Time; 2) Materials and components; 3) External services 4) Other costs, such as fines and rehabilitation.	They did not investigate the ratio	Denmark	Construction, cleaning service, and furniture
Waehrer *et al.* (2007)	***Direct costs:*** 1) Payments for hospital, physician, and allied health services 2) Rehabilitation, nursing home care, home health care, medical equipment, burial costs	They did not investigate the ratio	U.S.	Construction

Reference	Cost typology	Indirect to direct costs Ratio	Data source	Industrial sector
	3) Insurance administrative costs for medical claims 4) Payments for mental health treatment, police, fire, emergency transport, coroner services 5) Property damage ***Indirect costs:*** 1) Victim productivity losses which include wage losses and household production losses 2) Administrative costs which include the cost of administering workers' compensation wage replacement programs and sick leave. ***Quality of life costs*** 1) Pain and suffering that victims and their families			

The various components of indirect costs originate from studies that have been focused on accident costs in industries other than construction (e.g., furniture, forestry, chemistry, cleaning service, financial service, and manufacturing). Nonetheless, as shown in Table 2.2, the components of indirect accident costs from various industries demonstrate strong similarities. Based on the literature review (see Table 2.2), a set of components of indirect accident costs in construction environment was identified. The indirect costs of accidents comprise the following 13 possible components:

- Lost productivity due to the injured worker (e.g., Heinrich, 1931; Simonds and Grimaldi, 1956; Hinze, 1991);
- Lost productivity due to crew of injured worker (e.g., Heinrich, 1931; Hinze,

1991; Monnery, 1999);

- Lost productivity due to other workers in vicinity of accidents (e.g., Heinrich, 1931; Laufer, 1987; Hinze, 1991);
- Losses due to replacement of the injured worker (e.g., Laufer, 1987; Everett and Frank Jr., 1996; Monnery, 1999);
- Lost productivity due to the investigation or inspections as a result of the injury (Simonds and Grimaldi, 1956; Head and Harcourt, 1997);
- Cost of supervisory or staff effort (e.g., Heinrich, 1931; Simonds and Grimaldi, 1956; Hinze, 1991);
- Losses due to damaged equipment or plant, property, material or finished work due to the accident (e.g., Heinrich, 1931; Brody *et al.*, 1990; Hinze, 1991);
- Cost of transporting injured worker (e.g., Simonds and Grimaldi, 1956; Hinze, 1991; Monnery, 1999);
- Consumption of first-aid materials in this accident (Hinze, 1991; Head and Harcourt, 1997);
- Additional work required as a result of the accident (e.g. cleaning, additional barriers and so on) (e.g., Simonds and Grimaldi, 1956; Laufer, 1987; Everett and Frank Jr., 1996);
- Fines and legal expenses (Leopold and Leonard, 1987; Head and Harcourt, 1997);
- Losses due to Stop Work Orders (SWO) issued to the project (disruption of schedules) (Brody *et al.*, 1990; Everett and Frank Jr., 1996);
- Additional benefits to the injured worker beyond the Work Compensation Act

(WCA) (Heinrich, 1931).

2.4.3 Ratio between indirect costs and direct costs of accidents

As indicated in Table 2.2, many studies which aimed at investigating the true accident cost came out with a ratio between indirect costs and direct costs of accidents. However, there is no generally accepted ratio between indirect and direct costs of accidents, as this ratio ranges from1:4.7 to 20.3:1 (see Table 2.2). Several reasons may explain the wide variety of this cost ratio.

- Firstly, there exist different definitions and components of direct and indirect accident costs, or insured and uninsured accident costs.
- Secondly, the direct or insured accident costs vary greatly with the different work injury compensation and insurance policies in different countries/regions.
- Thirdly, since indirect costs represent those intangible or never enter the accounting system, the data collected in this category are not as reliable as those direct/insured costs. The accuracy of the data depends largely on the quality of the survey and estimation methods.
- Finally, the studies listed in Table 2.2 were conducted in different industries such as construction, manufacturing, chemistry, and forestry. Industries differ regarding work characteristics and thus number and types of accidents (Rikhardsson and Impgaard, 2004). The nature of different production systems in different industries might explain part of the variation in the cost ratio. In short,

the scope of individual research was the major cause that leads to the wide range of the direct/insured and indirect/uninsured cost ratio in different studies.

Even in a focused study such as that conducted by Hinze (1991), the ratio between direct and indirect costs does not hold constant for every individual project. Heinrich (1931), the pioneer in safety research also conceded that the 4:1 ratio between indirect and direct accident costs does not hold true for every individual plant. Many factors that are related to the characteristics of an individual project or a contractor have been identified to have impact on the ratio.

2.4.3.1 Company size

The impacts of company size on the size of total safety costs were demonstrated in the research by Rinefort (1976), who investigated and compared the quantitative effects of safety control activities on work injury costs in large-size, medium-size, and small-size companies. The results of this research indicated that the variation of the effects of safety control activities on work injury costs could partly be explained by differences in company size. The argument by Rikhardsson and Impgaard (2004) further illustrates the influences of company size on the accident costs: ‘In larger companies the Occupational Health and Safety department is a staff function manned with a number of specialists and secretaries and functions under numerous policies, rules and regulations. Thus, when an accident occurs in larger companies more formal activities are initiated than in smaller companies. There are more people involved, there are more internal administrative processes that have to be complied with and more organisational levels have to be informed.' (p. 179)

2.4.3.2 Project size

According to Hinze (1991), the cost ratios between direct and indirect costs tend to increase with the project size. 'Larger projects generally employ greater numbers of workers resulting in work being performed in more crowded conditions. An injury would naturally be expected to have a broader indirect cost impact on a larger project. Larger projects are also associated with deeper hierarchy structures in which greater numbers of administrative and supervisory personnel become involved with injury reporting and accident investigations. It can be concluded that project size does have a significant role in influencing the cost ratios of injuries.' (Hinze, 1991: p. 9-10)

Rikhardsson and Impgaard (2004) found that production process vulnerability is considered as a very important determinant of occupational accident costs. They argued that if the employee is responsible for a key function in the production process or has key responsibilities and there is no immediate replacement available, then the accident costs are higher. Thus, it seems that the production process tends to be more vulnerable for smaller projects than the larger ones which employ more employees.

2.4.3.3 Type of contract

Hinze (1991) made a comparison of the cost ratios on different contract types such as lump sum contracts and cost reimbursable contracts and found that on medical case injuries, the cost ratios are significantly higher on cost reimbursable contracts. The essential differences between cost reimbursable contracts and lump sum contracts may explain some of the variations. It seems that injuries do not receive sufficient attention on lump sum projects. In fact, it may be argued that a poorly managed cost reimbursable contract provides an inherent incentive to increase costs.

2.5 Economic approaches to safety management

2.5.1 Loss control theory

The control of losses due to the defects of safety management has been recognized as an important function of business management (Miller and Cox, 1997; Lingard and Rowlinson, 2005). Loss control has been defined as '*a management system designed to reduce or eliminate all aspects of accidental loss that may lead to wastage of the organisation's assets including manpower, materials, machinery, manufactured goods and money*' (Ridley and Channing, 1999, p. 9).

Loss control management involves the application of sound management techniques to the identification and evaluation of the organisation's risk exposure, and the economic control of losses within an organisation (Bird and Loftus, 1976; Ridley and

Channing, 1999). It is principally an economic approach to risk management (Lingard and Rowlinson, 2005). Ridley and Channing (1999) further pointed out that, with the increase of the emphasis on the economic argument, the loss control techniques or activities have become more closely allied to economic matters.

The loss control theory stresses the importance of the selection of appropriate loss control activities based on effectiveness and economic feasibility and the implementation of the loss control programme within economic constraints (Bird and Loftus, 1976). It has prompted a growing interest in examining the economic feasibility of the expenditure on accident prevention as well as the effective allocation of resources within budget. The following two sections review the literature on the economic approaches and techniques to safety management.

2.5.2 Economic evaluation of safety investments

Various techniques and methods have been developed to justify the investments in accident prevention activities as well as the resource allocation within budget. Andreoni (1986) identified four categories of safety-related expenditure including the routine expenditure incurred before occupational injuries happen, the expenditure following the occurrence of an occupational injury, the expenditure associated with transferring the financial consequences of an occupational injury to an insurer, and the exceptional expenditure on prevention. Andreoni (1986) suggested that an organisation’s total safety expenditure, which is the sum of all of these costs in the four categories, is an important part of organisational costs. More meaningful cost-benefit analysis can be undertaken to examine whether the expenditure on accident prevention is commensurate with the expenditure arising from occupational injuries (Andreoni, 1986).

Table 2.3 lists the summary of prior research on economic evaluation of investments in safety control activities undertaken since 1990. These studies focused on resources allocation within fixed budget of safety activities and evaluation of the effectiveness or profitability of investments in accident prevention activities. The methods employed in those studies aimed at prioritizing the investments of safety interventions included cost-benefit analysis (Jervis and Collins, 2001), analytical hierarchy process method (Jervis and Collins, 2001), risk evaluation (Yoon and Moon, 2000), accident scenario generation (Kim *et al.*, 2006), and multiobjective optimization (Kim *et al.*, 2006). In those studies aimed at justifying the investments in workplace safety, cost-benefit analysis was the most commonly used technique (Harms-Ringdahl, 1990; Lanoie and Tavenas, 1996, 1998). In order to facilitate the cost-benefit analysis of safety investments, an evaluation process (Riel and Imbeau, 1996), an accounting framework (Riel and Imbeau, 1996), and a Tool Kit for self evaluation were proposed (Amador-Rodezno, 2005). Although cost-benefit analysis has been recognized as a useful way to evaluate the investments in workplace safety, a salient limitation of applying this method, which lies in the difficulties in predicting the benefits of investments in safety, was also pointed out by many researchers (Rikhardsson and

Impgaard, 2004). Noticeably, most of the studies reviewed demonstrate the positive impacts of investments in certain safety interventions on the improvement of safety performance.

Table 2.3: List and Summary of Previous Studies on Economic Evaluation of Investments in Safety Control Activities

Source	**Summary of Research**	**Method**	**Industrial Sector**
Harms-Ringdahl (1990)	Safety work was divided into three categories, namely system investigation, implementation of measures, and the effect on the improved system. Costs and benefits of safety work were estimated to facilitate the cost-benefit evaluation. Results show that systematic safety work was economically beneficial in all case studies, and then the cost-benefit evaluation model worked practically.	Cost-benefit evaluation	Pulp and paper; sanitary.
Riel and Imbeau (1996)	This paper described the analysis of quantifiable health and safety costs and the allocation procedure of insurance costs for a particular type of coverage mechanism in Canada. The evaluation process and the accounting framework proposed in this paper will help to perform cost-benefit evaluation of safety interventions in future.	Activity-based Costing (ABC) method	Manufacturing
Lanoie and Tavenas (1996)	This paper present a rigorous econometric analysis to assess how many accidents have been prevented by the participatory ergonomics program so as to compute the direct and indirect costs avoided as a result of such accident reduction. The program was proved to be profitable for the firm.	Cost-benefit evaluation	Warehouse
Lanoie and Tavenas (1998)	This paper provides a cost-benefit analysis of the passage from a mechanical to a manual handling system, which aimed at reducing workplace accidents, that took place in the early 1990s at a warehouse in Montreal. Results show that the demechanization of the handling system has indeed been profitable for the firm.	Cost-benefit evaluation	Warehouse

Source	**Summary of Research**	**Method**	**Industrial Sector**
Yoon and Moon (2000)	The paper proposes a new quantitative method of supporting business decision-making while investing safety related facility and service. This method suggests the priority of investments relevant to safety within limited budget, so most possible hazards can be removed or the company may not invest money for the acceptable hazards depending on the budget.	Risk assessment	Petrochemical industry
Jervis and Collins (2001)	This paper quantitatively examines the relative benefits and resource costs associated with the major Voluntary Protection Programs (VPP) elements. To target limited resources for maximum impact, the analytical hierarchy process is used to rank the identified elements based on their benefit-to-cost ratio. Safety managers can then use this information to focus and direct their programs.	Cost-benefit analysis; Analytical hierarchy process (AHP)	Not specified
Farrow and Hayakawa (2002)	This paper introduced a real options approach for decision making in the private sector. This approach provides an important alternative to the standard phrase that (marginal) benefits should equal (marginal) costs. When maintaining safety is the default activity, in the real options framework, the usual cost of a safety investments with irreversible consequences can be economically justified up to a multiple of the usual benefits (damages avoided) with the multiple to be determined by the particular problem. The result is an economic decision gage that determines if it is optimal to invest in safety even if the estimated costs significantly exceed the estimated benefits.	Real options approach	Private sector; industries are not specified.
Amador-Rodezno (2005)	A Tool Kit (TK) was developed to enable managers and line workers in garment factories to self-diagnose plant and workstation hazards and to estimate the costs and benefits of investing in OSH as a way to improve productivity and competitiveness. This instrument integrates epidemiologic, risk assessment, clinic, engineering, and accountability issues. Through the application of the TK in industries, employers are now aware of the financial rewards of investing in OSH.	Cost-benefit evaluation	Textile

Source	Summary of Research	Method	Industrial Sector
Kim *et al.* (2006)	This paper developed a new systematic method of finding the most cost-risk-effective investments scenario set. The method uses the automatic accident scenario generation technique first to find a set of the most dangerous scenarios. Then it uses the multiobjective optimization method to decide the priority of the investments.	Accident scenario generation Multi-objective optimizat-ion	Chemical Process industries
Huang *et al.* (2007)	This study explored how senior financial executives or managers of medium-to-large companies perceive important workplace safety issues. The three top-rated safety priorities in resource allocation reported by the participants are overexertion, repetitive motion, and bodily reaction. A majority of participants believed that the indirect costs of accidents were higher than the direct costs. Money spent improving workplace safety was believed to have significant returns. The perceived top benefits of an effective workplace safety program were increased productivity, reduced cost, retention, and increased satisfaction among employees.	Qualitative study	All industries

2.5.3 Safety costs/investments optimization

Recognizing the potential of safety investments to reduce the risk of high injury cost, researchers become more concerned about the concept of “optimum safety investments”, as from an economic perspective there appears to be an optimal level of emphasis to be placed on safety (Hinze, 2000; HSE, 1993b). The concept of optimum safety investments states that a company would invest a certain amount of dollars in safety which will coincide with the minimal point of total safety costs (Diehl and Ayoub, 1980). Theoretical/hypothetical analyses (Brody *et al.*, 1990; HSE, 1993b; Laufer, 1987a, b) and empirical investigations (Tang *et al.*, 1997) have been conducted to apply the concept of optimum safety investments to workplace safety management.

Laufer (1987a, b) demonstrated the application of the concept of optimum safety investments through the hypothetical changes in the method of determining insurance premiums in Israel and in management’s perception of accident prevention costs. Figure 2.4 illustrates Laufer’s hypothetical analysis, which demonstrates the importance of changing management perceptions regarding prevention costs. In Laufer’s (1987a, b) hypothetical analysis, a hyperbole $PC=a/FR$ was used to represent the function of the relationship between safety investments and safety performance, with PC = the accident prevention costs (investments) expressed as a percentage of the wage, and FR = accident frequency per 1000 workers.

In Figure 2.4, situation (A) depicts the dependency of accident costs on accident frequency (insured and uninsured) when Social Security, which insures labor accidents, is alone in tying the premium to past safety level. Premiums for general liability and property damage handled by private firms remain unaffected by safety records. As far as prevention costs are concerned, management believes that, for 2.5% of labor costs, accident frequency will be reduced from the current Israeli average of 140 to 100.

In situation (B) private insurance companies relate premiums to safety records. Assuming research had improved the efficiency of prevention programs and was followed by proper training of management, their perception of prevention costs should change. Management now believes that 2.5% of labor costs will reduce accident frequency substantially to 25. Applying the principle of optimum safety cost, Figure 2.4 illustrates how safety prevention costs changes from 2.5% to 1.4% and how total safety costs changes from 6.0% to 2.8% (Laufer, 1987b).

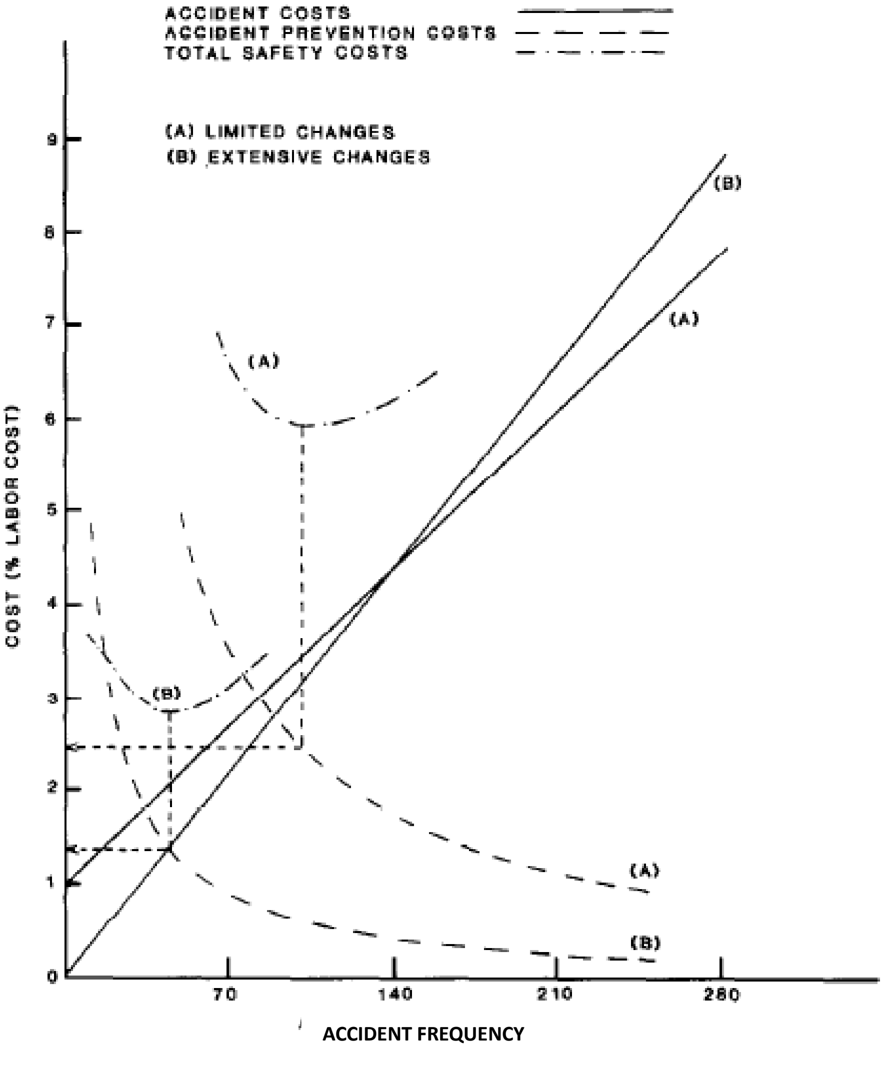


Figure 2.4: Hypothetical Projection of the Changes in Insurance Premium and Management's Perception of Accident Costs (Source: Laufer, 1987b)

Brody *et al.* (1990) applied the concept of optimum safety investments to demonstrate the importance of indirect accident costs. They developed a graphical model showing the impact of indirect accidents cost (IC) on the overall OHS cost (OHSC), safety prevention cost (PC), and the degree of risk (see Figure 2.5, 2.6 and 2.7). Their analysis was also based on the hypothetical relationships among safety prevention cost, accident cost, and the degree of risk. Brody *et al.* (1990) postulated that employers are unable to perceive the totality of AC and that decision-making is therefore a function of “perceived reality” rather than “true reality” (Landy, 1985). Figure 2.5 depicts the perceived accident costs (without considering the indirect accident costs), prevention costs and optimum degree of risk, which coincides with the minimal overall OSH costs.

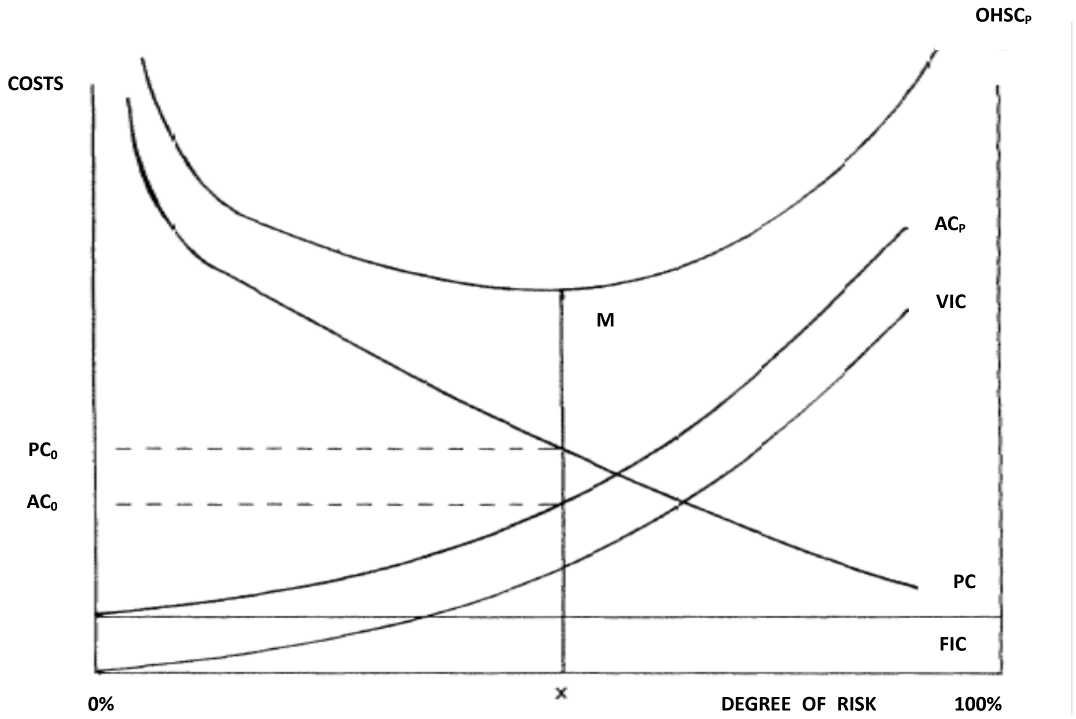


Figure 2.5: Perceived Accident Costs, Prevention Costs and Optimum Degree of Risk (Source: Brody et al., 1990)

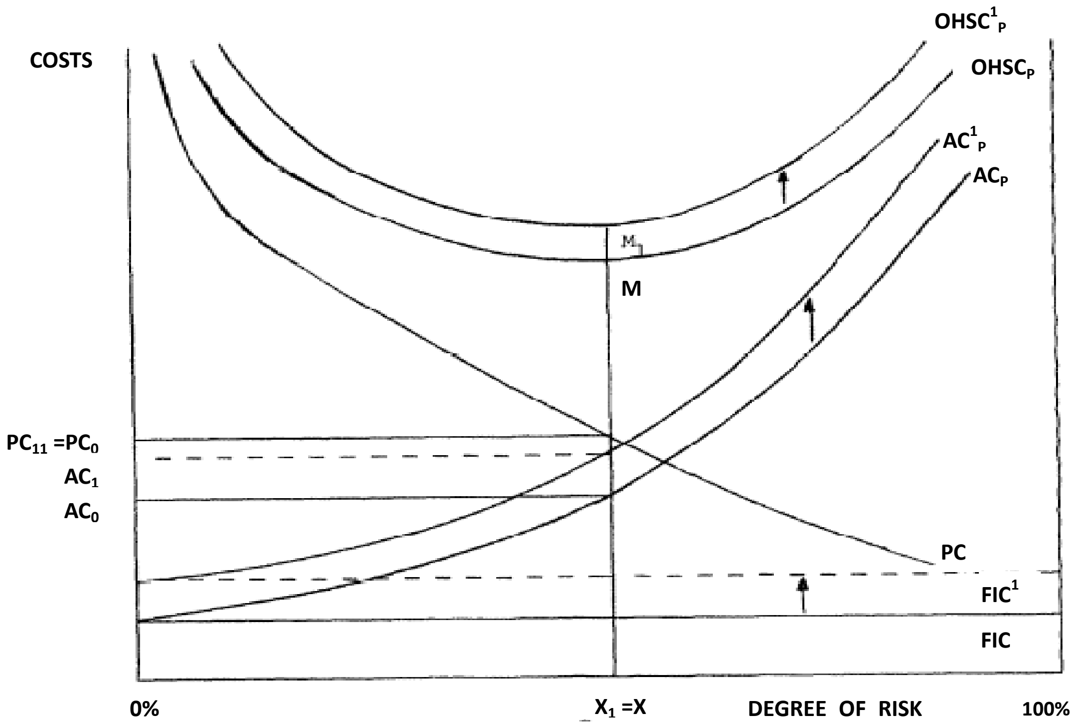


Figure 2.6: Increase in Fixed Insurance Costs, Prevention Costs and Optimum Degree of Risk (Source: Brody et al., 1990)

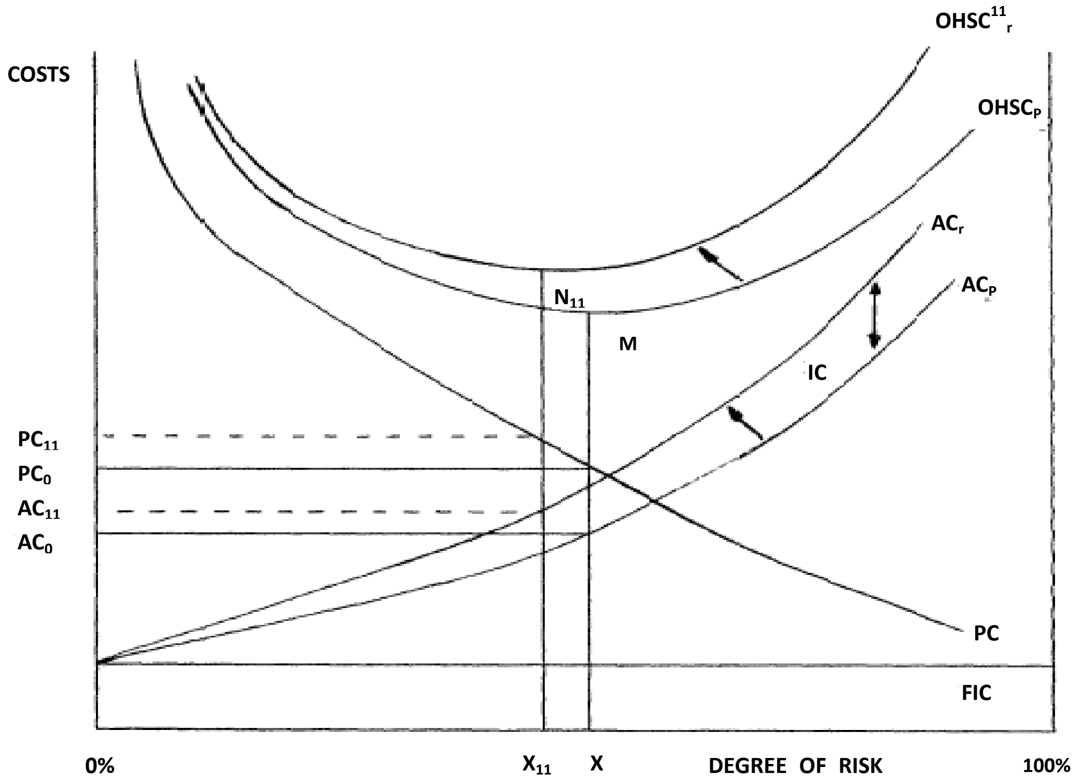


Figure 2.7: Indirect Costs, Real OHS Costs and Increased Prevention Costs (Source: Brody et al., 1990)

PC has a negative slope since, as these are increased, the degree of risk declines. Perceived accident cost (AC_p) is the sum of the fixed insurance costs (FIC) and variable insurance costs (VIC) and has a positive slope since the variable cost component is a direct function of the degree of risk. The $OHSC_p$ curve is the vertical sum of the PC and AC_p curves. The point, M, on the $OHSC_p$ curve minimizes total health and safety costs with PC_0 in prevention costs and AC_0 as perceived AC at X degree of risk. Figure 2.6 describes the hypothetical impact of increase in fixed insurance costs on PC, AC_p and $OHSC_p$. Figure 2.7 demonstrates the effects of adding indirect costs (IC) to AC_p.

Laufer (1987a, b) and Brody *et al.* (1990)'s studies were carried out based on the hypothetical relationship among safety investments, accidents cost, and safety performance. The hypothetical analyses by Laufer (1987a, b) and Brody *et al.* (1990) shed light on the concept of "*optimum safety costs*". As their studies were without the support of empirical evidence, there is a need for empirical examinations on optimum safety costs. This need was addressed by Tang *et al.* (1997) in their empirical research on safety cost optimization of building projects in Hong Kong.

In Tang *et al.*'s (1997) study, a relationship was obtained between accident costs and safety performance (measured by accident occurrence index). Similarly, a relationship was found between the safety investments and the safety performance. Based on the two curves, a new curve was obtained to describe the relationship between the total safety costs (the sum of safety investments and accident costs) and safety performance. As can be seen in Figure 2.8, the optimal level of safety investments of a building project could be determined. The optimal safety investments on a building project were found to be about 0.6% of the contract sum. The total cost to the contractor was found to be 0.82% of the same.

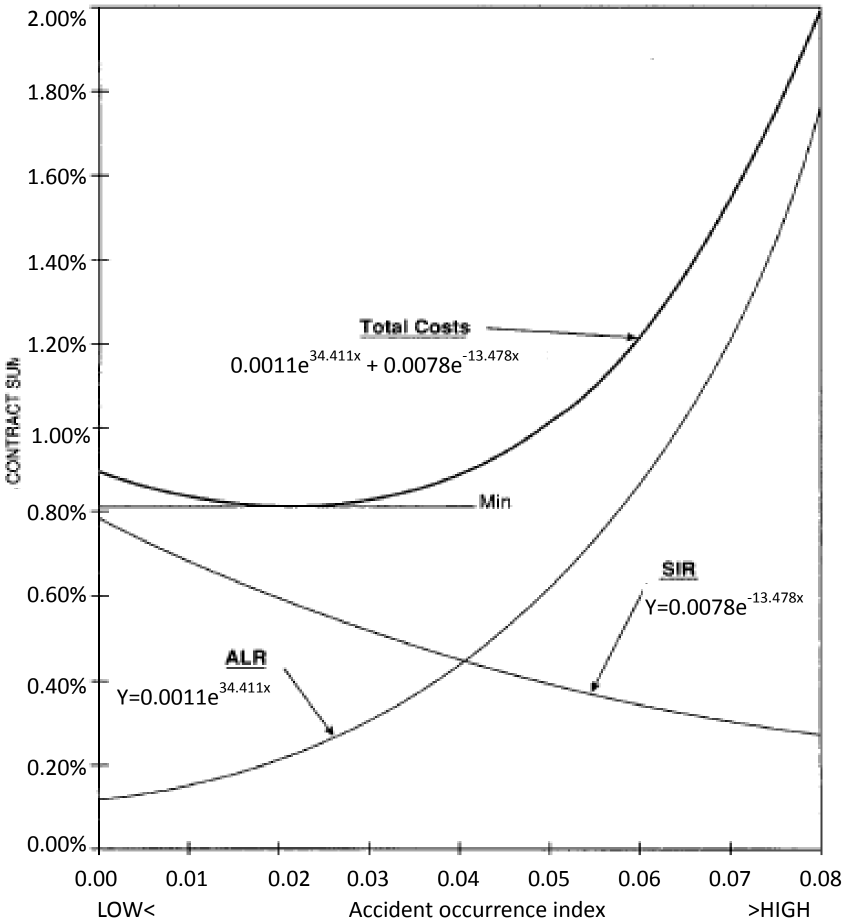


Figure 2.8: Accident Costs, Safety Investments and Total Costs Curves (Source: Tang et al., 1997)

Tang *et al.*'s (1997) empirical study adds valuable insight into the relationship among safety investments, accident costs, total safety costs, and safety performance. Functions and curves for the relationship between these factors were developed.

Although it quantified the minimal level of safety investments required for building projects in Hong Kong, some limitations of this study seem to be prominent. Much of the analysis in their research was based on speculation and assumption. For example, the exponential relationship between safety costs/investments and safety performance seems to be a "rule of thumb" relationship instead of any theoretically derived relationship. Thus, Tang *et al.*'s (1997) study lacked rigorous mathematical analysis on the relationships between safety investments, accident costs and safety performance.

The optimal safety investments formula (presented as the percentage of contract sum) found by Tang *et al.* (1997) is a coarse measure because the formula is universal for any type of building project regardless of the characteristics of an individual project. The formula also cannot be tailored for an individual project, whereas studies have shown that the initial project hazard level and project/contractor safety culture level do have impacts on the safety performance. The functions describing the relationship among safety investments, overall safety costs, accident costs and safety performance obtained by Tang *et al.* (1997) failed to show the integration of the influences of project hazard level and safety culture level.

2.6 Summary

A review of the accident causation theories reveals that the accidents could be somewhat prevented through management efforts. The safety performance of building projects is associated with the level of management efforts in accidents prevention, the inherent project hazards and non-human related events. The management efforts could be in the form of physical input such as the investments in safety personnel, safety facilities and equipments, safety training, and other safety related activities, and cultural input such as the cultivation of safety culture in construction sites. The inherent project hazard is a natural part of the initial construction site conditions owing to the scope and location of the project. Non-human related events like natural disasters are beyond control and prediction.

The review of the relationship between safety investments and safety performance shows that there is a popular assumption that higher level of safety investments tends to be associated with better safety performance. However, little empirical evidence was found to support this assumption. The relationship between safety investments and safety performance is still debatable among literature. It is still unclear whether their relationship is affected by other factors.

The categorization of accident costs into direct and indirect costs or insured and uninsured costs implies that focus on the direct costs may fail to reveal the true losses to employers due to an accident. Many of the losses incurred by an accident are “hidden” and difficult to quantify. These “hidden” costs may be significant, and some may be particularly prominent in construction industry. Therefore, both direct and indirect costs of accidents need to be examined to reflect the true costs of accidents to an employer.

Studies have been done to examine the economic feasibility of the expenditure on accident prevention as well as the optimal level of safety investments. A review of these studies shows that the investments on certain safety interventions are profitable. Most of the studies which shed light on the principle of optimum safety costs were based on the hypothetical relationship among safety investments, accident costs, and safety performance without the support of empirical evidence. Tang *et al.*'s (1997) study appears to be the only empirical study on the optimization of safety investments of building projects. However, Tang *et al.*'s (1997) study failed to: (1) explain why safety performance was weakly related to safety performance; (2) develop rigorous mathematical models on the relationships among safety investments, accident costs and safety performance; and (3) integrate the impacts of project hazard level and safety culture level in the optimization of safety investments. More insights on these issues are likely to enhance our understanding of the optimization of safety investments.

CHAPTER THREE

THEORETICAL FRAMEWORK

CHAPTER 3: THEORETICAL FRAMEWORK

3.1 Introduction

This chapter presents the theoretical framework for this research. Synthesizing the research problems, identified knowledge gap and literature review, the research hypotheses are developed, and a conceptual framework is developed.

3.2 Relationship between safety investments and safety performance

3.2.1 Implications of accident causation theories

Accident causation theories developed by many researchers (see Section 2.2) suggest that the level of OHS risk of building projects is associated with the inherent hazard level in the project and the level of human efforts in accidents prevention (Teo and Feng, 2011). Human endeavors could be in the form of physical input such as the investments in safety personnel, safety facilities and equipments, safety training, and other safety related activities, and cultural input such as the cultivation of safety culture in construction sites (see Sections 2.3 for a detailed discussion). Previous studies have examined the impacts of individual factors on safety performance, whereas no studies have been conducted to investigate the combined effects of the three factors namely safety investments, safety culture and project hazard. It is possible that safety performance of building projects is the result of the interactions of safety investments, safety culture and project hazard. The effect of any factor on safety performance may vary with the changes of the other two factors.

3.2.2 Risk compensation theory

Although technological advances have made the world safer and healthier, researchers have noted that some safety interventions, which had clear objective safety benefits, had failed to achieve the forecast savings in lives and injuries (e.g., Adams, 1982; Evans, 1986; Sagberg *et al.*, 1997). Adams (1982) examined the efficacy of seatbelt legislation through a comparative study of road accident fatality statistics from 18 countries and found that there was no correlation between the passing of seat belt legislation and the total reductions in injuries or fatalities. Sagberg *et al.* (1997) investigated drivers’ responses to airbags and antilock brakes and found that drivers of cars with airbags and antilock brakes tend to compensate by closer following, more lane changes and a lower rate of seat-belt use, which accounted for the failure of airbags and antilock brakes to result in any measurable improvement in road safety. Shealy (2008) who studied skiing and snowboarding injuries for more than 30 years found that the usage of ski helmets did not reduce fatalities and helmeted skiers tend to go faster. These studies have suggested that individuals will react to environmental changes in a compensatory fashion so that riskier behaviours result from perceptions that the environment has become safer.

Risk compensation theory states that individuals will behave less cautiously in situations where they feel "safer" or more protected (Peltzman, 1975). Peltzman (1975) proposed such compensation mechanism to explain why some safety interventions have produced negligible results. According to Peltzman (1975), drivers simultaneously experience the competing demands of lower risks (i.e., lower probability of death from an accident) and what Peltzman calls ‘‘driving intensity’’ (i.e., arriving at the destination more quickly, thrills, etc.). When safety devices are added, or the use of them is mandated, the risks associated with higher driving intensities are essentially lowered, e.g., drivers face a lower probability of death with the use of seat belt. Peltzman (1975) found that, under safer environment, drivers tend to increase speed rather than enjoy the increased safety associated with driving at the same speed. Peltzman’s (1975) theory suggests that individuals tend to adjust their behaviours in response to perceived changes in risk (Stetzer and Hofmann, 1996).

An associated theory is known as risk homeostasis, which was developed by Wilde (1982). Risk homeostasis theory had its genesis in highway and vehicle safety studies. Wilde (1982) defined the theory as the degree of risk-taking behaviour and the magnitude of loss, due to accident and lifestyle-dependent disease, being maintained over time unless there is a change in the target level or risk. Wilde (1982) further defined target risk as the level of risk a person chooses to accept to maximize the overall expected benefit from an activity. Wilde (1982) postulated that safety intervention feedback, together with anticipation, lead to adaptive behaviour that has a stabilizing effect on accident risk, even when the technology itself is safer.

In the construction context, risk compensation theory (Peltzman, 1975) and risk homeostasis theory (Wilde, 1982) have implications for the safety interventions. The effect of safety investments in physical protections and safety facilities, which aim to make the workplace safer, could be undermined by workers' compensatory behaviours, especially when the project hazard level is low. This is because working in the environment with lower hazard level may reinforce workers' perception that the environment is safer, which could lead to riskier behaviours of workers. The risk homeostasis theory (Wilde, 1982) suggests that the degree of risk-taking behaviour will be maintained over time unless there is a change in the target level or risk. The safety culture theory (see Section 2.3.2) implies that safety culture could impact upon workers' perceptions of OSH risks and safety behaviours. Therefore, it is possible that the effect of safety investments on safety performance of building projects could be affected by safety culture and project hazard level. Thus, based on the accident causation theories (see Section 2.2), the risk compensation theory and the risk homeostasis theory, the first hypothesis and sub-hypotheses are set out. The factors and how they are related to each other are described in Figure 3.1.

Hypothesis 1 – Safety performance of building projects is determined by the level of safety investments, safety culture level and project hazard level as well as the interactions among the three variables.

Hypothesis 1.1 – Safety performance of building projects varies positively with the level of safety investments.

Hypothesis 1.2 – Safety performance of building projects varies positively with the level of safety culture.

Hypothesis 1.3 – Safety performance of building projects varies inversely with the project hazard level.

Hypothesis 1.4 – The effect of safety investments on safety performance varies with the project hazard level.

Hypothesis 1.5 – The effect of safety investments on safety performance varies positively with the level of safety culture.

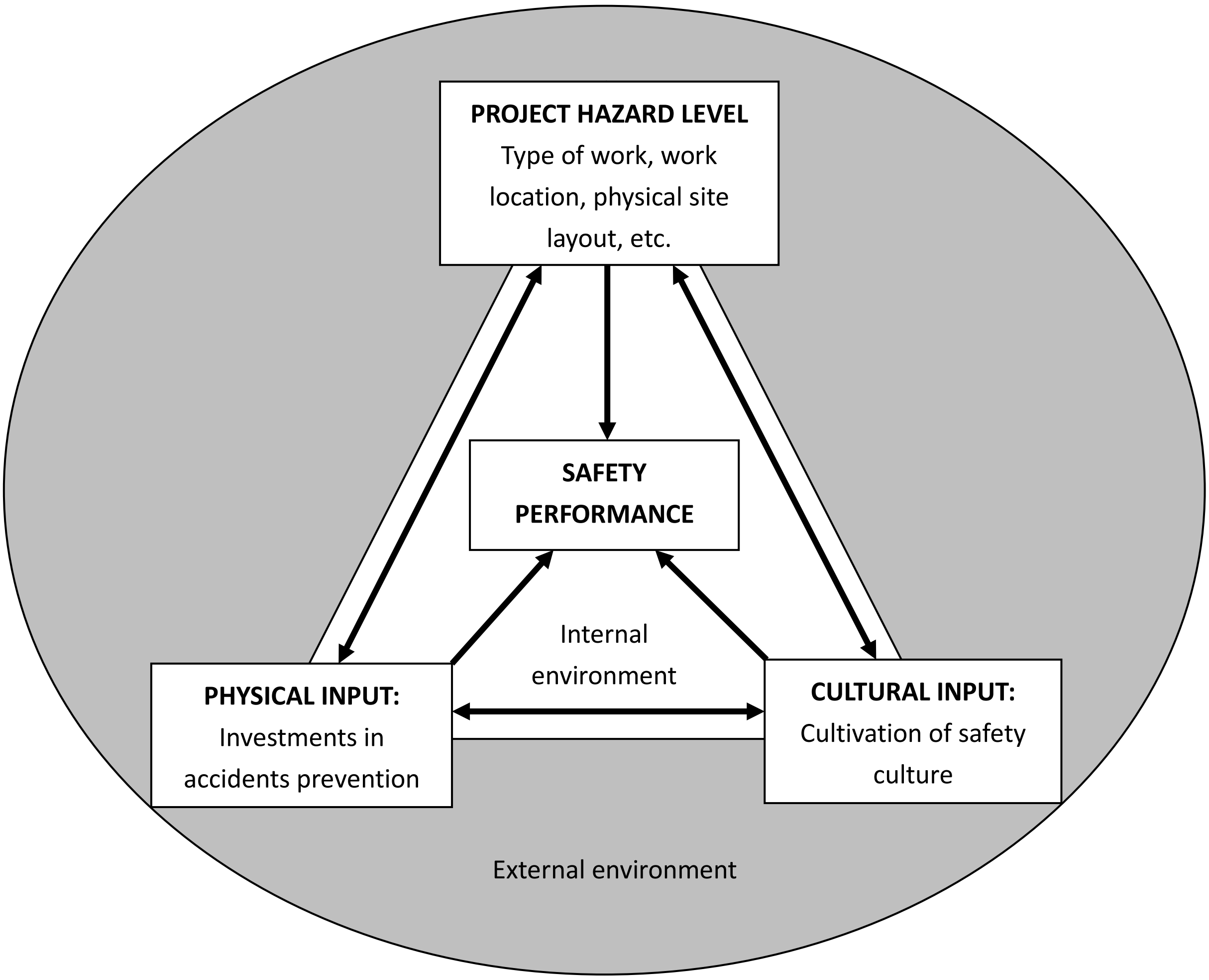


Figure 3.1: Factors Determining Safety Performance of Building Projects

3.3 Relationship between costs of accidents and frequency of accidents

Based on the definition of accident (see Section 1.7.1), an accident is any unintended event which causes bodily injury to a person in the course of a person’s work. Various losses would be incurred by the injured worker(s) after the occurrence of an accident. The total costs of accidents to a building project are the sum of the losses incurred by all the accidents occurred in the project. The accident costs theories (see Section 2.4 for a detailed discussion) suggest that the total costs of accidents to a building project are influenced by not only the frequency of accidents but also the severity of accidents of the project. From the definition and assessment of project hazard (see Section 2.3.3), it is possible that higher level of project hazard (i.e. greater heights of building, more work in confined spaces, and so on) is associated with greater chance of severe accidents, which would incur more medical expenses, more compensation for the injured workers and longer period of absence of injured workers. Moreover, the components of indirect accident costs suggest that the indirect accident costs of building projects are likely to be influenced by project characteristics, e.g. project size, contractor size, project duration, and so on. For example, when an accident occurs in larger companies or larger projects, it is possible that more people would be involved and more internal administrative processes need to be complied with. Therefore, based on the accident costs theory, the concept of project hazard and the indirect accident costs theory, the second hypothesis and its sub-hypotheses are set out. The factors and how they are related to each other are described in Figure 3.2.

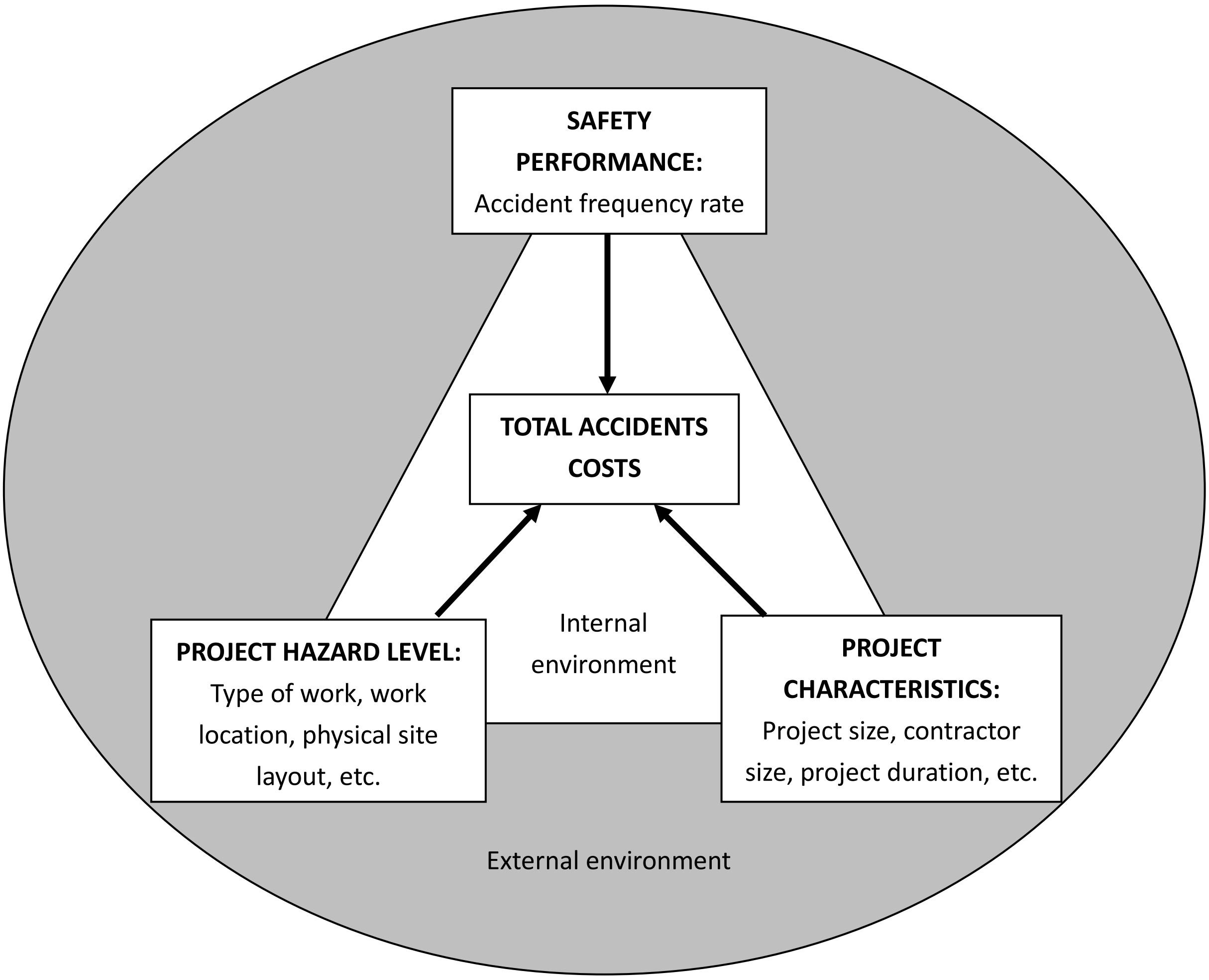


Figure 3.2: Factors Determining Total Accidents Costs of Building Projects

Hypothesis 2 – The total accident costs of a building project vary with the accident frequency rate, project hazard level and project characteristics.

Hypothesis 2.1 – The total accident costs of a building project vary positively with the accident frequency rate.

Hypothesis 2.2 – The total accident costs of a building project vary positively with the project hazard level.

Hypothesis 2.3 – The total accident costs of a building project vary with the project characteristics.

Hypothesis 2.4 – The effect of accident frequency rate on the total accident costs of a building project varies with the project hazard level.

3.4 Financially optimum level of safety investments

3.4.1 The law of diminishing marginal returns

In economics, the *"law of diminishing returns"* states that as the amount of any one input is increased, holding all other inputs constant, the amount that output increases for each additional unit of the expanding input will generally decrease (Pindyck and Rubinfeld, 1997). The concept of diminishing returns can be traced back to the concerns of early economists such as Johann Heinrich von Thünen, Turgot, Thomas Malthus and David Ricardo. Malthus and Ricardo, who lived in 19th century England, were worried about that land, a factor of production in limited supply, would lead to diminishing returns. In the famous treatise, *An Essay on the Principle of Population*, Malthus (1798) analyzed population growth and noted the potential for populations to increase rapidly, and often faster than the food supply available to them. To give a mathematical perspective to his observations, Malthus (1798) proposed the idea that population, if unchecked, increases at a geometric rate (i.e. 1, 2, 4, 8, 16, etc.), whereas the food-supply grows at an arithmetic rate (i.e. 1, 2, 3, 4, 5 etc.). In order to increase output from agriculture, farmers would have to farm less fertile land or farm with more intensive production methods. In both cases, the returns from agriculture would diminish over time, causing Malthus and Ricardo to predict population would outstrip the capacity of land to produce, causing a Malthusian catastrophe (Johns and Fair, 1999, p790). The law of diminishing returns, first thought to apply only to agriculture, was later accepted as an economic law underlying all productive enterprise (Spillman and Lang, 1924). This principle implies that the marginal physical product of an input will fall with increasing investment of other inputs, as the system involved approaches perfection, market saturation or natural environment limits of one or another kind.

Based on the law of diminishing returns, given a certain level of cultural inputs in activities to improve safety performance and a certain level of inherent hazard level of the project, each additional unit of physical inputs are supposed to yield less and less output (improvement of safety performance). Figure 3.3 proposed by Lingard and Rowlinson (2005) shows that the law of diminishing marginal returns applies to prevention or risk reduction expenditure (safety investments). When the physical input is small (and the culture level and hazard level are fixed), small increments in the physical input add substantially to output as the investments are allocated to specialized tasks. Eventually, however, the law of diminishing returns applies. When there are too many investments in activities to improve safety performance, part of the investments may become ineffective, and the marginal product of safety investments falls. In this situation, as suggested by Lingard and Rowlinson (2005), some judgement as to the acceptability of the risk is required and some investments may be deemed to be uneconomical.

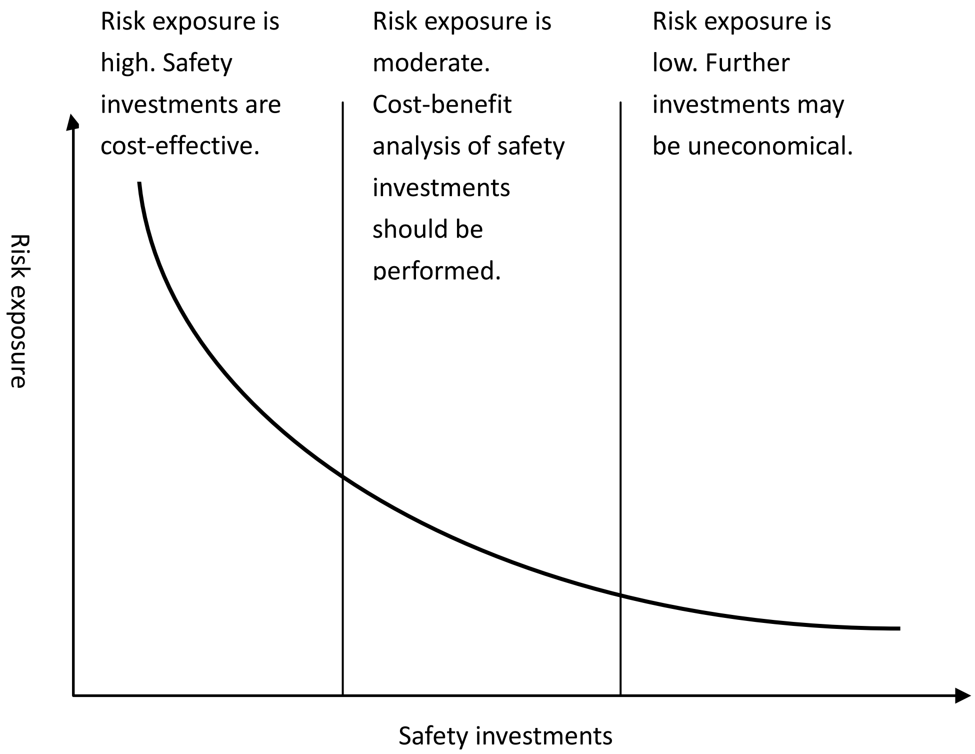


Figure 3.3: Safety Investments and Risk Exposure (Source: Lingard and Rowlinson, 2005, p190)

3.4.2 The principle of optimum total safety costs

A basic assumption of most economic analysis of firm behaviour is that a firm acts so as to maximize its profits by setting out where marginal costs equal marginal revenue (e.g., Menger, 1871; Marshall, 1890; Varian, 1992). Hirshleifer (1980) wrote, 'According to the classical formulation, the aim of the firm as a decision-making agent is to maximize (economic) profit*'* (p. 265). Economists (e.g., Albrecht, 1983; Varian, 1992) have defined economic profit as the difference between the revenue a firm receives and the costs that it incurs. Given a certain output, one fundamental way to achieve profit maximization would be minimizing the costs of the actions taken to produce such an output. The total safety costs of a building project include safety investments and accident costs. If the output of a building project remains constant, the marginal cost of production will be increased when the total safety costs rise. Thus, an underlying motive to drive safety investments of building projects is to reduce production or operating costs for the sake of profits (Grimaldi and Simonds, 1975).

According to Hopkins (1995), in Australia, economic rationalism has informed many policies of deregulation of workplace rations and occupational health and safety. Economic rationalism, which was firstly used by Watson (1979), reflects the notion that if markets are left to operate freely with minimal government interference, optimal outcomes will be achieved. ‘Safety pays’ is regularly used by government as a way of motivating employers to attend to occupational health and safety (Hopkins, 1999). The UK HSE (1993b) seems to embrace an economic rationalist perspective in suggesting that it is possible to identify a level of OHS risk that represents the optimum economic level of prevention and incident costs (Lingard and Rowlinson, 2005). Hinze (2000) suggests that from an economic perspective, three appears to be an optimal level of emphasis to be placed on safety. The economically optimal level of safety investments is the point at which the cost benefits from improving OHS are just equal to the additional costs incurred (Lingard and Rowlinson, 2005), which is referred to as the principle of optimum safety costs (Diehl and Ayoub, 1980). The economically optimal level of safety investments imply that a company would invest a certain amount of dollars in safety which will coincide with the minimal point of total safety costs.

The above analysis implies that economic theories may apply to workplace safety management. The law of diminishing marginal returns, the principle of profit maximization, and the economic rationalism suggest that it is possible to achieve financially optimum outcomes for occupational safety and health management. Thus, a proposition states that the financially optimum level of safety investments is determined by the minimization of total safety costs.

3.5 Theoretical framework

The main hypotheses and their sub-hypotheses developed in Sections 3.2 and 3.3 are integrated into a theoretical framework for this study. As shown in Figure 3.4, this theoretical framework describes how the various factors are related to each other.

Figure 3.4 shows that safety performance is related to safety investments, safety culture level and project hazard level as well as the interactions among the three variables (Hypothesis 1). From literature review (see Section 2.3.1), seven components of safety investments were identified. They are: (1) staffing cost; (2) training cost; (3) safety equipments and facilities cost; (4) safety inspections and meetings cost; (5) safety promotion cost; (6) safety incentive cost; and (7) safety innovation cost. More details can be found in Section 4.3.1.3 which presents the measurement of safety investments.

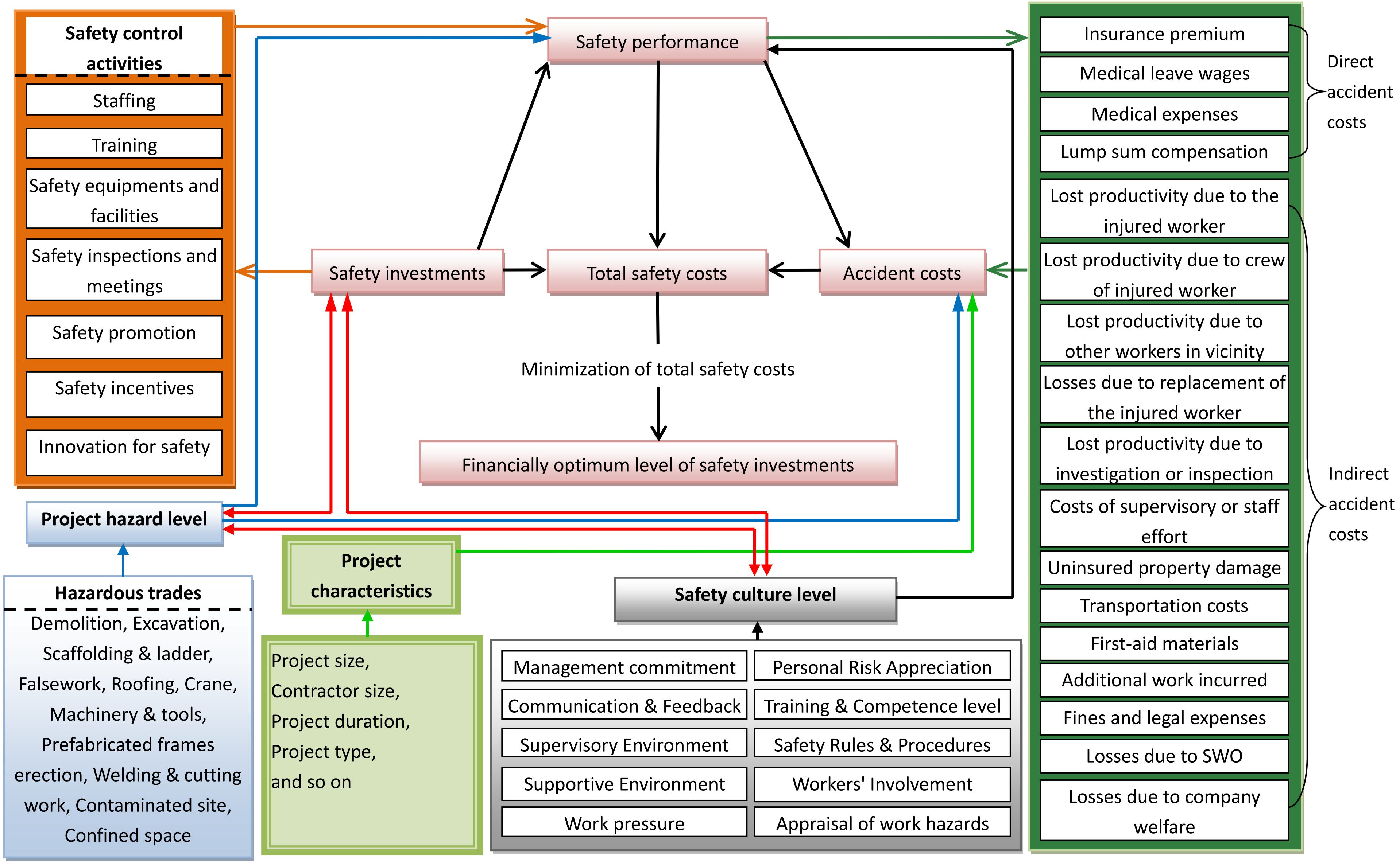


Figure 3.4: Theoretical Framework for this Study

Eleven hazardous trades of building projects were identified to assess the project hazard level (see Section 2.3.3). These hazardous trades include: (1) demolition; (2) excavation; (3) scaffolding & ladder; (4) falsework; (5) roofing; (6) crane; (7) machinery & tools; (8) prefabricated frames erection; (9) welding & cutting work; (10) contaminated site; and (11) work in confined space. More details can be found in Section 4.3.1.5 which presents the measurement of project hazard level.

Ten dimensions were identified to assess the level of safety culture of building projects (see Section 2.3.2). They are: (1) management commitment; (2) communication and feedback; (3) supervisory environment; (4) supportive environment; (5) work pressure; (6) personal risk appreciation; (7) training and competence level; (8) safety rules and procedures; (9) workers’ involvement; and (10) appraisal of work hazards. More details can be found in Section 4.3.1.4 which presents the measurement of safety culture.

Figure 3.4 also shows that accident costs of building projects are related to safety performance, project hazard level and project characteristics (Hypothesis 2). Project characteristics include project size, contractor size, project duration, project type, and so on. A review of studies on accident costs (see Section 2.4) shows that the total accident costs comprise the direct accident costs and indirect accident costs. The direct accident costs comprise insurance premium, medical leave wages (not covered by insurance policy), medical expenses (not covered by insurance policy), and lump sum compensation (not covered by insurance policy) (see Section 2.4.1). More details can be found in Section 4.3.1.2 which presents the measurement of accident costs. The following cost items were identified to measure the indirect accident costs of building projects:

- Lost productivity due to the injured worker;
- Lost productivity due to crew of injured worker;
- Lost productivity due to other workers in vicinity of accidents;
- Losses due to replacement of the injured worker;
- Lost productivity due to the investigation or inspections as a result of the injury;
- Cost of supervisory or staff effort;
- Losses due to damaged equipment or plant, property, material or finished work due to the accident;
- Cost of transporting injured worker;
- Consumption of first-aid materials in this accident;
- Additional work required as a result of the accident (e.g. cleaning, additional barriers and so on);
- Fines and legal expenses;
- Losses due to Stop Work Orders (SWO) issued to the project (disruption of schedules); and
- Additional benefits to the injured worker beyond the Work Compensation Act (WCA).

Lastly, Figure 3.4 shows that the financially optimum level of safety investments is determined by minimization of total safety costs (refer to the proposition in Section 3.4.2). The total safety costs are the sum of safety investments and accident costs of building projects. Please refer to Section 3.4.2 for detailed explanation of the proposition about the financially optimum level of safety investments.

3.6 Summary

In this chapter, two main hypotheses and their sub-hypotheses were postulated. Based on the accident causation theories, the risk compensation theory and the risk homeostasis theory, the first main hypothesis postulates that safety performance of building projects is determined by safety investments, safety culture and project hazard level as well as their interactions. Based on the accident costs theory, the concept and measurement of project hazard and the indirect accident costs theory, the second main hypothesis postulates that the total accident costs of a building project are impacted by the accident frequency rate, project hazard level and project characteristics. Based on the law of diminishing marginal returns, the principle of profit maximization, and the economic rationalism, a proposition states that the economically optimum level of safety investments is determined by minimization of total safety costs. A theoretical framework was developed to integrate all the hypotheses and describe how the various factors are related to each other.

CHAPTER FOUR

RESEARCH METHODOLOGY

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents the research methodology of this study. Section 4.2 describes the research design, sampling method, and sample size. Section 4.3 focuses on the data collection method, measurement of research variables, development of data collection instrument, pilot study and process of data collection. Section 4.4 discusses the methods of data analysis and model validation. Section 4.5 reports the characteristics of the sample including the response rate, profile of projects, and profile of respondents.

4.2 Research philosophy and research design

In research design, the methodological approaches in finding solutions to the research problem are defined. Creswell's (2003) research design framework provided a guideline to aid the design of an appropriate research approach for this study. Creswell (2003) proposed that three elements should be defined in the research design: philosophical assumptions about knowledge claims; general procedures of research; and the detailed procedures of data collection, analysis and writing. Thus, in defining an appropriate research strategy for this study, three questions were addressed: (1) what knowledge claims are made? (2) what approaches of inquiry are appropriate? and (3) what methods of data collection and analysis are required?

4.2.1 Methodological paradigms

Research is underpinned by the researcher's perceived assumptions of the world, and the means by which the world may be well understood (e.g., Remenyi *et al.*, 1998; Trochim, 2000). Paradigms provide a conceptual framework through which to view the world (Hesse-Biber and Leavy, 2006). There are traditionally two contrasting paradigms to research: induction and deduction. The deductive reasoning tends to proceed from the general statement to the specific statement, while inductive reasoning tends to go from the specific example to the general statement (Fellows and Liu, 2008). Trochim (2000) notes that the deductive approach involves the processes of identifying theories, generating hypotheses, and making observations to test the hypotheses for confirmation; whilst the inductive approach involves the activities of making specific observations, discovering patterns, and generating general conclusions or theories.

The distinctive ontological (i.e. whether the object of investigation is the product of consciousness or whether it exists independently) and epistemological (i.e. what our grounds of knowledge are) perspectives that the two research paradigms represent provides a useful framework for discussing the philosophical assumptions that underpin various research designs (Remenyi *et al.* 1998; Bryman and Bell 2003). From the epistemological and ontological perspectives, deductive research represents the positivist and objectivist perspectives to enquiry, symptomatic of a deterministic philosophy (Remenyi *et al.* 1998). A prominent feature is that the researcher is supposed to maintain objectivity throughout the investigation so that the research is devoid of bias from personal values. The induction paradigm represents the interpretivist and constructivist approaches to enquiry, with emphasis on generation of multiple meanings (Remenyi *et al.* 1998).

Different methodological paradigms imply different research approaches and methods. Deduction is widely used in ‘natural sciences’ and emphasizes the use of ‘natural sciences’ methods, mainly quantitative methods; whilst induction is most likely to use qualitative methods (Dainty 2008; Fellows and Liu 2008). Quantitative approaches adopt ‘scientific method’ in which initial study of theory and literature yields precise aims and objectives with proposition(s) and hypotheses to be tested (Fellows and Liu 2008). Qualitative approaches involve research in which an exploration of the subject is undertaken without prior formulations (Fellows and Liu 2008). The use of either quantitative or qualitative approaches, which are underpinned by the positivist and interpretivist worldviews, has generated a lot of debates across various disciplines, which indicate that none of the single approaches may be claimed to be absolutely perfect or adequate, as each has specific strengths and weaknesses, and advantages and disadvantages (e.g. Patton 1980; Trochim 2000; Mangan *et al.* 2004; Kumar 2005). ‘The measurement and analysis of the variables about which information is obtained in a research study are dependent upon the purpose of the study’ (Kumar 2005).

4.2.2 Towards a research strategy for this study

Knowledge claim addresses the philosophical assumptions relating to how to learn and what will be learnt during the inquiry. This requires being explicit about claims of what knowledge is (ontology), how we know it (epistemology), what values go into it (praxiology) and how to express it (rhetoric), enabling the processes for studying it (methodology) to be clearly defined (Creswell, 2003). This study aims to investigate the financially optimum level of safety investments for building projects by studying the relationships between safety investments, accident costs and safety performance (see Section 1.4). The phenomenon under study is amenable to the objectivist view of the social world since the relationships between safety investments, accident costs and safety performance are assumed to undeniably exist and be independent of the researcher. The information needed to shed light on the financial aspects of construction safety is mainly objective and quantitative. Thus the ontological position with regards to the phenomena of this study was objectivism/realism. A positivistic approach was adopted to achieve the research aims. The philosophical stance assumes that the research is independent of and neither affects nor is affected by the subject of the research. Using the positivistic approach, 'the researcher is unbiased (i.e., neutral and devoid of personal opinion and unsupported views) when applying accepted research techniques and focus on the means or mechanisms of how the social world works, not on ends, values, or normative goals' (Neuman, 2003).

From the perspective of objectives of a research study, research can be classified as exploratory, descriptive, correlational, or explanatory (Kumar 2005). Exploratory research aims to investigate phenomena and identify variables and generate hypotheses for further research (Fellows and Liu 2008). It is usually carried out with the objective either to explore an area where little is known or to investigate the possibilities of undertaking a particular research study (Kumar 2005). Descriptive research seeks to systematically describe all the elements of a phenomenon, process or system, or describe attitudes towards an issue (Kumar 2005; Fellows and Liu 2008). It is often used as the next step to exploratory research to construct paradigms that offer a more complete theoretical picture through either qualitative or quantitative data (Saunders *et al.* 2003; Sekaran 2003). The main emphasis in a correlational research study is to discover or establish the existence of a relationship/ association/ interdependence between two or more aspects of a situation. Explanatory research attempts to clarify why and how there is a relationship between two aspects of a situation or phenomenon (Kumar 2005; Fellows and Liu 2008).

The objectives of this study indicate that this study contains elements of correlational (e.g. it sought to explore the relationships between safety investments, accident costs and safety performance) and explanatory (e.g. it sought to explain how safety investments impact on the safety performance of building projects) research. The objectives and hypotheses imply that: (1) this study aims to quantify the variation in a phenomenon (i.e., the financial aspects of workplace health and safety); (2) the information is gathered using predominantly quantitative variables (e.g., safety investments, accident costs, safety performance, etc.); and (3) the analysis is geared to ascertain the magnitude of the variation. The aim of this research and the epistemological and ontological implications for the research strategy therefore favoured the use of quantitative approach to achieve the research aims. The appropriateness of the use of a positivist paradigm and its concomitant use of quantitative approaches in this study was further reinforced by the apparent dominance of the positivist paradigm and quantitative research approaches in construction management research, albeit the view that the feasibility of totally objective and accurate observation are being increasingly challenged (Smyth and Morris 2007; Dainty 2008; Fellows and Liu 2008). For example, Dainty's (2008) examination of the papers published by Construction Management and Economics (volume 24) throughout 2006 revealed that 71% (76) used quantitative methods, while only 8.4% (9) employed qualitative methods with a further 11.2% (12) using mixed methods.

4.2.3 Research approaches

As discussed in Section 4.2.2, quantitative research approaches are considered as appropriate for this study. Three main study designs are commonly employed in conducting quantitative research: experimental; quasi or semi-experimental; and non-experimental (Kumar 2005).

In true/classical experiments, the researchers have direct control over the research environment through randomization and manipulation (Kerlinger, 1973). They may manipulate and control selected independent variables to determine their individual effects or combined effects on the dependent variable. Through the high degree of control of extraneous variables in true experiments, cause-effect relationship can be established. ‘However, the high level of control needed to assure internal validity often results in very restrictive conditions which make true experiments appear artificial and, thus, lack external validity’ (Tuuli 2009, pp.122). Babbie (1992) noted that experimental designs are suitable for research involving relatively limited and well defined concepts and propositions. In Quasi-experimental research, the researcher has little or no control over the allocation of the treatments or other factors being investigated. The key difference between experimental design and Quasi-experimental design is the lack of random assignment (Dooley, 2001). Without random assignment, participants do not have the same chance of being assigned to a given treatment condition, thus the researcher has less control over the independent variables than in experimental design. However, quasi-experiments may achieve higher external validity than true experiments by using subjects in their natural settings.

Both experimental design and Quasi-experimental design were considered inappropriate for this study for the following reasons:

- Since construction projects generally cost millions of dollars, and they are often under the influence of many factors, it is not practical to conduct an experimental research study.

- Parties’ interactions in a construction process are complex and difficult to model in the laboratory.
- Because of complexities involved in the interactions of psychological factors, environmental factors, and behavioural factors in safety issues, a study of this nature would require real life investigation rather than laboratory experiments.

Non-experimental research does not allow the researcher to manipulate and control over the selected independent variable(s) to determine its/their effect(s) on the dependent variable(s). According to Kerlinger (1973), non-experimental design is the only way to study many real world organisational phenomena. There are five common types of non-experimental research designs, namely case studies, surveys, correlation or regression, comparisons, and historical designs. Generally, case studies are more appropriate for in-depth understanding of particular instances; surveys are used to obtain broad population characteristics and reasons for certain actions or preferences; correlation or regression analysis is used when experimental control is difficult or impossible; comparative research seeks to explain similarities and differences between two or more groups; and historical research seeks to explain the past to understand or draw lessons for the present and future (Tan, 2004).

The aim of this study is to investigate the desirable level of safety investments in building projects by studying the relationships between safety investments, safety performance and accidents costs of building projects. Based on the hypotheses presented in Chapter 3, this study seeks to establish the underlying associations between variables, e.g., the relationships between safety performance, project hazard level, safety investments and safety culture, the relationships between safety performance and accident costs, the relationships between safety performance and total safety costs, and so on.

According to Tan (2004), a more flexible way of examining the relationships between variables is to use correlation or regression analysis. *'Correlation analysis investigates associations among variables, and a regression model specifies the relation between independent and dependent variables' (Tan, 2004, p129).* Tharenou *et al.* (2007, p.47) summarized the circumstances that are most suitable for the use of correlation or regression research design. These circumstances include:

- to test a theory that includes not just the independent variables and dependent variables, but also perhaps mediator variables or moderator variables;
- to test the hypotheses/research questions on a large sample of people;
- to examine real-life settings and use people facing those situations every day;
- to examine the extent to which the dependent variable and each independent variable are related;
- to generalize the findings – therefore, a large sample is chosen to be representative of a particular and predefined population;
- to test questions when there is a solid literature base (i.e., theory, empirical

studies) from which to choose the variables to measure in the survey; and

- to assess the effects of several variables (e.g., independent variables) while taking into account other variables (e.g., controls such as individuals' demographics, or organisational characteristics).

Based on the aim of this study and the circumstances for the use of regression/correlation design summarized by Tharenou *et al.* (2007), a regression/correlation design is considered to be appropriate for this study. This is because, in a regression/correlation research design, many different types of relationships can be assessed (Tharenou *et al.*, 2007), e.g., relationship between dependent and independent variables, interrelationship between independent variables, inclusion of mediator variables which intervene between the independent and dependent variables (see Section 4.4.4), inclusion of moderator variables which moderates the strength and/or direction of relationship between the dependent and independent variables (see Section 4.4.3), and so on.

In formulating the research design, it is critically important to accurately identify the unit of analysis, such as the individual or the group (Fellows and Liu, 2008). Fellows and Liu (2008) further noted that '*Failure to do so may result in two errors of logic: the ecological fallacy and reductionism.*' The unit of analysis in this study is defined as a constructor's project. Safety investments and accident costs are confined to those incurred by building contractors (including main contractors and subcontractors) within the project. Consultant and client projects were not targeted in the research design. For the contractor's project in this context, typical members include: project manager/director, site manager, site engineer, site quantity surveyor, planning engineer, safety manager, safety officer, safety supervisor, foreman, etc. The unit of analysis has implications for the determination of sampling method, which will be discussed in Section 4.3.3.

4.3 Data collection

4.3.1 Development of data collection instrument

Based on the theoretical framework presented in Section 3.5, there are six major variables in this study. They are safety performance, safety investments, accident costs, safety culture, project hazard level, and project characteristics. Among these variables, some can be directly observed or well documented; while some are unobservable variables (latent variables) which must be inferred from measurable or observable indicators (manifest variables). Each research variable needs to be well defined and operationalized before the data collection instrument is developed.

4.3.1.1 Safety performance

There are various measures of safety performance for construction projects. They are generally classified as reactive measures (after the event) and proactive measures (Cooper and Phillips, 2004). Typical examples of reactive measures are to calculate the incident rate and accident rate of recordable injuries, loss-time injuries, first aid injuries, etc. (Hinze and Godfrey, 2003). The incidence/accident rate of injuries is the measure most frequently employed as an industry standard. Some researchers argue that the reduction in accident and incident rates provides the best results measure of the safety performance(Clarke, 1998), and accident or injury data of various forms have been used in a number of studies (Tang *et al.,* 1997; Mearns *et al.*, 2003; Niskanen, 1994; O'Toole, 2002; Silva *et al.*, 2004; Vredenburgh, 2002; Zohar, 2000). The attraction of using the reactive indicators is that they provide a tool enabling the safety performance of one organisation to be compared with another organisation or across the industry. The information about recorded injuries can also be used by management to gain insights about accident causation provided an accident investigation is conducted (Hinze and Godfrey, 2003). Despite this, the reactive measures are criticized for their focus on the past records and negative aspects of safety performance (i.e. system failure) (Hinze and Godfrey, 2003; Cooper and Phillips, 2004; Holt, 2005). As noted by Holt (2005), ‘*because the numbers of recorded incidents and injuries are relatively low in most organisations, they tend to produce a limited amount of information about risk and there is a temptation to believe that all is well*’ (p. 14).

Many researchers advocates the use of proactive measures (e.g. jobsite safety inspections, behaviour-based worker observations and worker safety perception surveys), which focus on current safety activities to ascertain system success rather than system failure (Hinze and Godfrey, 2003; Cooper and Phillips, 2004; Holt, 2005). For instance jobsite safety inspections can be made on jobsites to assess physical working conditions and also to evaluate worker safety behaviour. They can be very helpful in giving information that can provide direction for improving jobsite conditions and worker behaviour. The weakness of jobsite safety inspections lies in the consistency with which the data are actually collected. The results of inspections cannot be compared between different inspectors unless all the inspectors are trained to consistently assess the nature of physical conditions and worker behaviour (Hinze and Godfrey 2003). Worker safety perception surveys can be used to provide information that tends to be an overall indication of the success (or failure) of management to instil a safety consciousness on the jobsite. Weaknesses of using worker safety perception surveys may include that they tend to be difficult to administer, that they may not be conducted as often as might be warranted, and that the data can also be difficult to analyze (Hinze and Godfrey, 2003). The behaviour-based worker observation which is derived from behavioural safety is thought to be one of the most useful proactive indicators of current safety performance (Reber *et al.*, 1989; Cooper and Phillips, 2004). They can be implemented in many ways, among which the most common way is for a worker to function as an observer of another worker. The advantage of the observed percent safe is that it offers a method of measuring the potential for harm, independent of the accident record. Disadvantages may include the need to change safety climate for both management and workforce to adopt this method, and employee suspicion of hidden motives for the observations (Holt, 2005).

In general, there is no single measure of safety performance can be said to be superior to others. The choice of safety performance measures or indicators relies upon the purpose of measuring and resources availability. The reactive measures are most suitable to be used for the evaluation of past safety efforts or for the purpose of comparison; while the proactive measures can be used to indicate whether the current systems or efforts are working properly (Hinze and Godfrey, 2003; Holt, 2005). The proactive safety performance measures are not suitable to be used in this study because this study collected data from completed building projects. The accident rates were adopted by this study to measure safety performance of building projects. This is because: (1) the purpose and design of this research indicate that the accident rates enable the comparison of safety performance among different building projects; (2) because the report of incidence is required by law in Singapore, the records of injuries are available for all building projects operated in Singapore; and (3) In Singapore, there are standard formulas for calculating frequency and severity rates of accidents, which are used by government (e.g. MOM) to produce statistical information or reports relating to WSH issues across all industries. In Singapore, both “Accident Frequency Rate” (AFR) and “Accident Severity Rate” (ASR) are used by Ministry of Manpower (MOM) to measure workplace safety performance. The formulas for calculating AFR and ASR are described as below (MOM, 2008a):

$$\text{AFR} = \frac{\text{Total No. of Accidents}}{\text{Total No. of Man-hours Worked}} \times 1{,}000{,}000$$

$$\text{ASR} = \frac{\text{Total No. of Man-days Lost to Accidents}}{\text{Total No. of Man-hours Worked}} \times 1{,}000{,}000$$

where total number of man-days lost to workplace accidents = $\sum_{i=1}^{n}$ (Number of Man-days Lost to the i^{th} Workplace accident), where n is the total number of accidents in a project.

4.3.1.2 Accident costs

Based on the literature review (see Section 2.4), accident costs are the sum of the direct costs and indirect costs. The direct costs of accidents tend to be those associated with the treatment of the injury and any unique compensation offered to workers as a consequence of being injured (Hinze, 1997). In Singapore, the direct accident costs are typically the costs covered by Work Injury Compensation Act (MOM, 2008b). Thus, the direct costs of accidents are the sum of the following four components:

- **Insured costs (DC_1).** The accident costs covered by the insurance policy were measured by the insurance premium paid by contractors;
- **Medical leave wages (DC_2)** (not covered by insurance policy): as measured by complementary medical leave wages that were not covered by insurance policy;

- **Medical expenses (DC_3)** (not covered by insurance policy): as measured by the medical expenses that were not covered by insurance policy; and
- **Lump sum compensation for Permanent Incapacity (PI) or death (DC_4)** (not covered by insurance policy): as measured by the compensation for PI or death that was not covered by insurance policy.

Although different definitions exist for the indirect costs of accidents, in general they are regarded as consisting of all the costs that are not covered by worker's compensation insurance (Hinze, 1991). In this study, the indirect accident costs are those costs that are not covered by Work Injury Compensation Act of Singapore. Based on the literature review, 13 costs items were identified to be indirectly related to the occurrence of the accidents.

- **Lost productivity due to the injured worker (IC_1)**: as measured by lost labor time on the day of injury, lost labor time due to follow-up treatment, and lost labor time due to reduced efficiency after resuming work;
- **Lost productivity due to the crew of injured worker (IC_2)**: as measured by lost labor time due to assisting injured worker and reduced crew productivity due to working shorthanded;
- **Lost productivity due to other workers in vicinity of accident (IC_3)**: as measured by lost labor time due to watching events and discussing accidents;
- **Losses due to replacement of the injured worker (IC_4)**: as measured by

reduced efficiency of replacement worker and the costs incurred by the recruitment, selection, and training of new workers to temporarily or permanently replace work accident victims;

- **Lost productivity due to investigations or inspections as a result of the accident (IC$_5$)**: as measured by the lost labor time due to interruption of production caused by accident investigation and safety inspection;
- **Cost of supervisory or staff effort (IC$_6$)**: as measured by lost staff time due to assisting injured worker, investigating accident, preparing reports, and accompanying the media, project owner, and/or regulatory inspector;
- **Damaged equipment or plant, property, material or finished work due to the accident (IC$_7$)**: as measured by the costs of replacing or repairing damaged materials and/or equipments, the costs of reconstruction of the damaged work, the productive time lost (interruption of production), and others;
- **Costs of transportation (IC$_8$)**: as measured by the costs of transporting injured worker;
- **Consumption of first-aid materials (IC$_9$)**: as measured by the value of first-aid materials consumed in the accident;
- **Additional work required as a result of the accident (IC$_{10}$):** as measured by the labor time used to clean the site, set up the additional barriers and so on;
- **Fines and legal expenses (IC$_{11}$)**: as measured by the fines and legal costs

imposed by OSHA or court systems due to the accident;

- **Losses due to Stop Work Orders (SWO) (IC_{12}):** as measured by the wages paid to workers during the period of Stop Work and the liquidated damages due to the Stop Work; and
- **Additional benefits to the injured worker beyond the Work Compensation Act (IC_{13})**: as measured by extra financial assistance or other welfare provided by contractors.

The total accident costs (TAC) are the sum of direct accident costs (DAC) and indirect accident costs (IAC). Three dimensionless quantities, the total accident costs ratio (TACR), the direct accident costs ratio (DACR) and the indirect accident costs ratio (IACR) were used to measure the level of TAC, DAC and IAC respectively and enable the comparison among projects of different sizes. TACR, DACR, and IACR were therefore defined as follows:

$$TACR = \frac{\text{Total Accident Costs (TAC)}}{\text{Contract Sum}} \times 100\%$$

$$DACR = \frac{\text{Direct Accident Costs (DAC)}}{\text{Contract Sum}} \times 100\%$$

$$IACR = \frac{\text{Indirect Accident Costs (IAC)}}{\text{Contract Sum}} \times 100\%$$

where TAC = DAC + IAC, DAC = $\sum_{i=1}^{4} DC_i$, and IAC = $\sum_{i=1}^{13} IC_i$ where DC_i is the i^{th} direct cost item and IC_i is the i^{th} indirect cost item.

4.3.1.3 Safety investments

Based on the literature review, safety investments comprise expenses for all kinds of accident prevention activities which were undertaken by the contractor's project organisation (including subcontractors). Those safety investments made by the contractor at the company level were allocated to individual projects; and these investments were also considered as part of the project's overall safety investments. The safety investments made by the other parties of the project (e.g., consultant and client) except for the contractors and subcontractors are not within the scope of this study.

The tangible part of safety investments consists of dollars spent on the accident prevention activities. There is, however, another part of safety investments, namely intangible safety investments, taking the form of time invested in the accident prevention activities, e.g. the time invested in safety training and orientation, the time invested in emergency response drills, the time invested in safety meetings and inspections, and other activities (Teo and Feng, 2011). This part of safety investments is always unobservable, and therefore tend to be neglected by practitioners (Teo and Feng, 2011). With consideration of both tangible and intangible parts, safety investments are the sum of the following components:

- **Staffing costs (C_1).** The safety staffing costs are measured by the salaries paid to safety personnel, such as safety managers, safety officers, safety coordinators, safety supervisors, lifting supervisors, administration support to safety personnel, and others. The safety staffing costs incurred at both project level and company level was collected. For those safety staffing costs incurred by head office (e.g., safety director, safety coordinator, administrative support to safety personnel, etc.), the respondents were requested to estimate the salaries of safety personnel on pro rata according to the number of projects supervised in the same period. As some of the safety personnel (e.g., director, administrative support, etc.) may be involved in other tasks besides safety related work (e.g. environmental work), the interviewees were required to estimate the percentage of time spent on safety work of the project for each safety personnel.

- **Safety equipments and facilities costs (C_2).** Safety equipments and facilities include Personal Protective Equipments (PPEs), safety fences, safety barricades, and any other facilities that have to do with the provision of safety on building sites. The costs of safety equipments and facilities include the purchase of equipments, materials, machines, and tools, and the costs of manpower for the installation and maintenance of these facilities.

- **Compulsory training costs (C_3).** Safety training costs comprise costs of compulsory safety training courses and costs of in-house safety training and orientation sessions. Compulsory safety training courses include safety training courses for project managers, safety training courses for foremen and supervisors, safety training courses for workers, and safety training courses for operators/signalmen. The costs of compulsory safety training costs are measured by the dollars paid for the external training institutes (e.g. BCA Academy and NTUC Learning Hub).

- **In-house safety training costs (C_4)**. In-house safety training activities consist of safety orientation before work commences each day, emergency response and drills for various possible situations, briefing on first-aid facilities, first aiders, and first-aid procedures, briefing on major hazards on site, safety workshops for supervisors and above, safety seminars and exhibitions, and demonstrations of safe work procedures and first-aid drills, and other in-house training activities. The costs of the in-house safety training activities are measured by the lost productivity due to the participation in these activities. Thus the interviewees were required to provide the information about the total number of participants, average hourly wages of the participants, and duration and frequency of each in-house training activity to facilitate the estimation of the costs of in-house safety training activities.

- **Safety inspections and meetings costs (C_5).** Generally, safety inspections and safety meetings do not involve direct monetary expenditures, nevertheless, the inspections and meetings always consume the productive time of the participants and may cause the interruption of some ongoing construction work. Therefore, the level of investments in safety inspections and safety meetings could be measured by the lost productivity due to the participation in the inspections and meetings and the interruption of ongoing construction work.

- **Safety incentives and promotions costs (C_6).** Safety incentives and promotions costs include the expenditures on the printing of pamphlets and posters, the production of safety advertising boards and banners, the organizing of safety campaigns, financial support for safety committees activities, the monetary rewarding of workers, management staff or subcontractors who achieve a good safety standard of work, and so on.

- **Safety Innovation costs (C_7).** Innovation for safety refers to the use of new technologies, methods, procedures, or tools in order to improve safety performance of the project. The costs of safety innovation are measured by estimating the direct investments in obtaining the innovations (e.g. purchase of new tools or technologies, costs of R&D, and training costs) and possible increased production costs or lost productivities incurred by the use of these innovations.

Close examination of these components could reveal that some components are determined by external industry or government regulations and some are determined by internal company or project OSH policy. Thus, safety investments could further be classified into two types, namely basic safety investments and voluntary safety investments (see Figure 4.1).

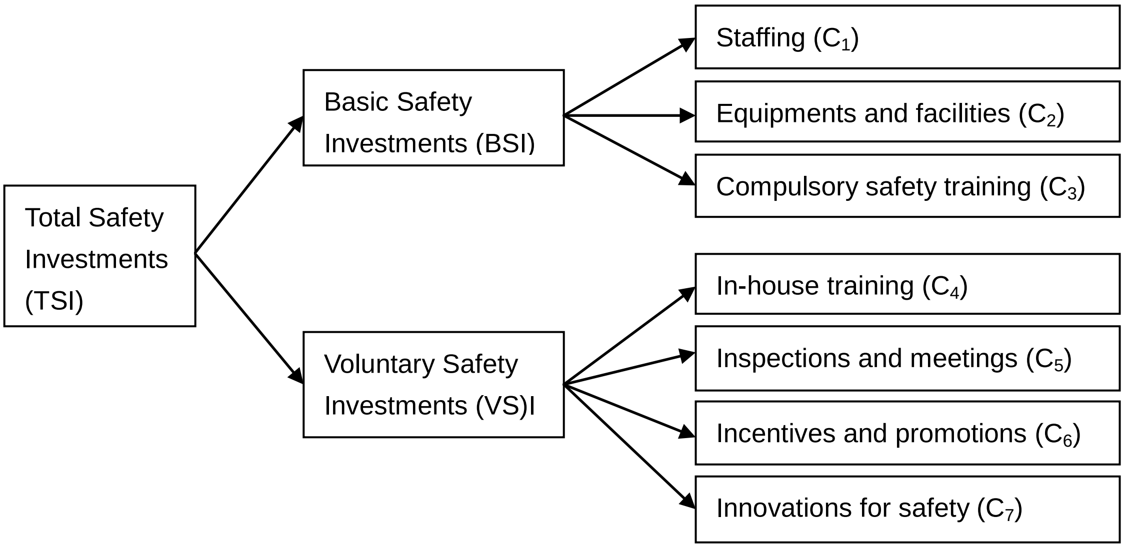


Figure 4.1: Components of Safety Investment

- *Basic safety investments (BSI)* are required by industry or government regulations and construction process on minimal safety standards. As a compulsory part of safety investments for any individual building projects in Singapore, BSI consists of those costs incurred by safety personnel, safety equipments and facilities, and compulsory safety training courses.

- *Voluntary safety investments (VSI)* are generally determined by individual companies or projects. This type of safety investments is incurred by the voluntary safety prevention activities such as in-house safety training and orientation, safety inspections and meetings, safety incentives and promotions, and innovative technologies, methods and tools designed for safety (4 "I" activities).

A dimensionless quantity, the Total Safety Investments Ratio (TSIR) was used to enable the comparison of the level of safety investments among projects of different sizes. TSIR is therefore defined as follows:

$$TSIR = \frac{\text{Total Safety Investments}}{\text{Contract Sum}} \times 100\%$$

where Total Safety Investments = $\sum_{i=1}^{7} C_i$, where C_i is the i^{th} safety investment component.

Similarly, two dimensionless quantities, Basic Safety Investments Ratio (BSIR) and Voluntary Safety Investments Ratio (VSIR) were used to enable the comparison of the level of BSI and VSI among projects of different sizes respectively. BSIR and VSIR are therefore defined as follows:

$$BSIR = \frac{\text{Basic Safety Investments}}{\text{Contract Sum}} \times 100\%$$

$$VSIR = \frac{\text{Voluntary Safety Investments}}{\text{Contract Sum}} \times 100\%$$

where Basic Safety Investments = $\sum_{i=1}^{3} C_i$, where C_i is the i^{th} safety investment component, and Voluntary Safety Investments = $\sum_{i=4}^{7} C_i$, where C_i is the i^{th} safety investment component

4.3.1.4 Safety culture

As discussed in Section 2.3.2, in order to determine the level of safety culture of an organisation, there is a variety of quantitative and qualitative data collection tools available that can be used to assess the safety culture, among which the safety climate survey is constantly utilized as a reliable indicator of the overall safety culture (e.g., O'Toole, 2002; Cox and Cheyne, 2000; Lee and Harrison, 2000; Teo and Feng 2009). Given the numerous definitions of safety culture and safety climate that have been proposed in the literature, it is not surprising that there is little consensus as to the factor structure of the safety climate questionnaire (Flin *et al.*, 2000; Mohamed, 2002; Toole, 2002; Mearns *et al.*, 2003). Table 4.1 lists the factor structure that has been found in previous safety culture/climate studies. The numerous inconsistencies and often idiosyncratic labelling of these factors creates difficulty in reconciling the variety of organizational indicators identified in previous studies, nonetheless, a closer examination of these various reports suggests that there are ten important factors of the safety climate questionnaire in construction environment. They include: management commitment, communication and feedback, supervisory environment, supportive environment, work pressure, personal appreciation of risk, training and competence level, safety rules and procedures, workers' involvement, and appraisal of work hazards.

The comprehensiveness of the above constituents was determined by the extensive review of the factor structure that has been found in previous safety culture/climate studies (see Table 4.1). The parsimony and adequacy of the theory were checked to further justify the choice of these ten factors. Parsimony requires a theory to be stated in the most economical way possible without oversimplifying the phenomena of interest (Fawcett, 2005). The question to be asked when evaluating the parsimony of the constituents is that 'are the constituents stated clearly and concisely' (Fawcett, 2005). Based on the literature review, these constituents clarify rather than obscure the concept of safety climate. In the following paragraph, the contents of the ten constituents are clearly stated. Adequacy requires the assertions made by the theory to be congruent with empirical evidence (Fawcett, 2005). The extent to which the constituents of safety climate questionnaire meet the criterion of adequacy was determined by means of examining the empirical data to determine the extent of their congruence with the theory. Mohamed (2002) used structural equation modeling to demonstrate that the ten constituents of safety climate are congruent with empirical evidence. Other related studies (e.g., Zohar, 1980; Fang et al., 2006) also provided empirical evidence that the ten factors are important in achieving a positive safety climate in construction site environments.

Table 4.1: Review of Safety Culture and Climate Indicators

Author(s)	Indicators
Zohar (1980)	▪ Importance of safety training programs; ▪ Management attitudes towards safety; ▪ Effects of safe conduct on promotion; ▪ Level of risk at work place; ▪ Effects of required work pace on safety; ▪ Status of safety officer; ▪ Effects of safe conduct on social status; ▪ Status of safety committee.
Cox and Cox (1991)	▪ Personal scepticism; ▪ Safeness of work environment; ▪ Individual responsibility; ▪ Effectiveness of arrangement for safety; ▪ Personal immunity.
Dedobbeleer and Beland (1991)	▪ Management commitment; ▪ Risk/involvement.
Ostrom *et al.* (1993)	▪ Safety awareness; ▪ Teamwork; ▪ Pride and commitment; ▪ Excellence; ▪ Honesty; ▪ Communications; ▪ Leadership and supervision; ▪ Innovation; ▪ Training; ▪ Customer relations; ▪ Procedure compliance; ▪ Safety effectiveness; ▪ Facilities.
Niskanen (1994)	▪ Work pressure; ▪ Supervision; ▪ Work value; ▪ Responsibility.
Coyle and Sleeman (1995)	▪ Maintenance and management issues; ▪ Company policy; ▪ Accountability; ▪ Training and management issues; ▪ Work environment; ▪ Policy and procedures; ▪ Personal authority; ▪ Training and enforcement of policy.
Lee (1996)	▪ Safety procedures: confidence in the safety procedures, safety rules, personal understanding of safety rules, perceived clarity

	of safety rules, permit to work system, confidence in the effectiveness of PTW, general support for PTW, and perceived need for PTW; ▪ Risks; Personal caution over risks, perceived level of risks at work, perceived control of risks in the plant, personal interest in job, job satisfaction, contentment with job, satisfaction with work relationships, and satisfaction with rewards for good work; ▪ Participation/ownership: Self-participation in safety procedures, perceived source of safety suggestions, perceived source of safety actions, and perceived personal control over safety; ▪ Design: satisfaction with design of plant, training, satisfaction with training selection, and satisfaction with staff suitability.
HSE (1999)	▪ Organizational commitment and communication; ▪ Line management commitment; ▪ Supervisor’s role; ▪ Personal role; ▪ Workmates’ influence; ▪ Competence; ▪ Risk taking behavior and contributory influences; ▪ Obstacles to safe behavior; ▪ Permit to work; and ▪ Reporting of accidents and near misses
Glendon and Litherland (2001)	▪ Communication and support; ▪ Adequacy of procedures; ▪ Work pressure; ▪ Personal protective equipment; ▪ Relationships; ▪ Health and safety rules.
Mohamed (2002)	▪ Commitment; Communication; ▪ Health and safety rules and procedures; ▪ Supportive environment; ▪ Supervisory environment; ▪ Workers’ involvement; ▪ Personal appreciation of risk; ▪ Appraisal of work hazards; ▪ Work pressure; ▪ Competence.
Itoh, Andersen and Seki (2003)	▪ Motivation; ▪ Satisfaction with own competence; ▪ Safety awareness of operation; ▪ Morale; ▪ Satisfaction with manual and checklists; ▪ Satisfaction with management system;

	▪ Trust in management.
Wiegmann *et al.* (2004)	▪ Organizational commitment; ▪ Management involvement; ▪ Employee empowerment; ▪ Reward systems; ▪ Reporting systems.
Fang *et al.* (2006)	▪ Health and safety attitude and management commitment; ▪ Health and safety consultation and training; ▪ Supervisor’s and workmate’s roles; ▪ Risk taking behaviour; ▪ Health and safety resources; ▪ Appraisal of health and safety procedure and work risk; ▪ Improper health and safety procedure; ▪ Worker’s involvement; ▪ Workmate’s influence; ▪ Competence.
Teo and Fang (2006)	▪ Communication & Feedback; ▪ Supervisory Environment & Supportive Environment; ▪ Health and Safety Rules & Procedures; ▪ Training Program & Competence Level; ▪ Health and Safety Investments; ▪ Workers' Involvement & Work Pressure; ▪ Personal Risk Appreciation & Appraisal of Work Hazards; ▪ IT Intelligence.

- *Management commitment (SC$_1$).* Management commitment stresses the role of management (including upper management and project management) in promoting safety. The greater the level of management commitment toward safety, the more positive the safety culture will be (e.g. Zohar, 1980; Mohamed,2002; Fang *et al.*, 2006). Management commitment was measured with four scale items, which were derived from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is ‘*Top management considers safety to be more important than productivity*’.

- *Communication and feedback (SC_2).* Both management communication and employee feedback are critical for suggesting safety improvements and reporting near misses as well as unsafe conditions and practices (Simon and Piquard, 1991). The more effective the organizational communication dealing with safety issues, the more positive the safety culture will be (e.g. Ostrom *et al.*, 1993; Mohamed,2002; Fang *et al.*, 2006). Communication and feedback was measured with five scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*Management clearly communicates safety issues to all levels within the organisation*'.

- *Supervisory environment (SC_3).* The success of a safety management system program relies not only upon the management commitment, but also upon the ability of supervisory personnel to ensure that the program is carried out during daily operations. The more safety aware and relationship oriented the supervisors, the more positive the safety culture will be (e.g. Niskanen, 1994; Mohamed,2002; Fang *et al.*, 2006). Supervisory environment was measured with five scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*Site management and supervisors see themselves as safety role models for all workers*'.

- *Supportive environment (SC_4).* Supportive environment refers to the degree of trust and support within a group of workers, confidence that people have in working relationships with co-workers, and general morale. The higher the level of support given by co-workers, the more positive the safety climate will be (e.g. Glendon and Litherland, 2001; Mohamed,2002; Fang *et al.*, 2006). Supportive environment was measured with five scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*As a group, workers maintain good working relationships*'.

- *Work pressure* (SC_5)*.* Work pressure refers to the degree to which employees feel under pressure to complete work, and the amount of time to plan and carry out the construction work. The higher the perception of valuing expediency (e.g. productivity) over safety, the less positive the safety culture will be (e.g. Glendon and Litherland, 2001; Mohamed,2002; Fang *et al.*, 2006). Work pressure was measured with four scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*Workers always work under a great deal of tension, and not given enough time to get the job done safety'*.

- *Personal appreciation of risk* (SC_6)*.* Attitudes toward safety have been found to be associated with personal perception of risks and individuals' willingness to take risks. The higher the level of workers' willingness to take risk, the less positive the safety culture will be (e.g. HSE, 1999; Mohamed,2002; Fang *et al.*, 2006). Personal appreciation of risk was measured with four scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*Workers have the right to refuse to work in unsafe and unhealthy conditions*'.

- *Training and competence level (SC$_7$).* Training and competence level addresses the general level of workers' qualifications, knowledge, and skills, with associated aspects related to selection and training. The greater one's experience and knowledge of safety issues and the more trainings received by workers, the more positive the safety culture will be (e.g. Zohar, 1980; Mohamed,2002; Fang *et al.*, 2006). Training and competence level was measured with seven scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*There is adequate safety training to site management team, such as supervisors and project management team members*'.

- *Safety rules and procedures (SC$_8$).* Rules and procedures are the core component of safety management systems. The more comprehensive of safety rules and procedures and the better the perception of safety rules and procedures, the more positive the safety culture will be (e.g. Coyle and Sleeman, 1995; Mohamed,2002; Fang *et al.*, 2006). Safety rules and procedures were measured with eight scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*Permit-To-Work (PTW) systems are established and implemented in your project*'.

- *Workers' involvement (SC_9).* Workers' involvement addresses the extent to which the workers are involved in safety activities, such as safety inspections, accident investigations, developing safety interventions and policies, reporting injuries and potentially hazardous situation, etc. The higher the level of workers' involvement in safety matters, the more positive the safety culture will be (e.g. Dedobbeleer and Beland, 1991; Mohamed,2002; Fang *et al.*, 2006). Workers' involvement was measured with four scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*Workers play an active role in identifying site hazards'*.

- *Appraisal of work hazards (SC_{10}).* Workplace hazards are defined as tangible factors that may pose risks for possible injuries or ailments. The better the implementation of a well established hazards analysis and risk assessment system, the more positive the safety culture will be (e.g. Lee, 1996; Mohamed,2002; Fang *et al.*, 2006). Appraisal of work hazards was measured with four scale items drawn from a variety of previous studies (e.g. Zohar, 1980; Mohamed, 2002; Teo *et al.*, 2004). A sample item is '*Potential risks and consequences are identified prior to execution*'.

The ten indicators and their respective attributes were listed in the questionnaire (see Appendix 1). All the scale items in the questionnaire were anchored with the statement '*Please indicate to what extent you agree or disagree (1 = strongly disagree,* *3 = neutral, and 5 = strongly agree) with each of the following statements based on the safety practices in your project by circling your responses using the following scale*'. To derive the overall score of safety culture level for a given project, the weights of all safety culture indicators and their measurement items need to be determined. Jia *et al.* (1997) note that the choice of a weighting method depends on one's knowledge of the underlying distributions of true weights. However, it appears that no research has been done to examine the weights or relative importance of safety culture indicators. This aspect may deserve further exploration in future studies. In such situation, the equal weights method, which requires minimal knowledge of the decision maker's priorities and minimal input from the decision maker, was employed. Jia *et al.* (1997) suggest that, if one has no information about the true weights, the expected value of the weights distribution is the equal weights vector defined by $w_i = 1/m$, where $i = 1, 2, \ldots, m$ and m is the total number of attributes. This method was popularized by an influential article by Dawes and Corrigan (1974), who argued that this method often produced decisions nearly as good as those based on optimal (e.g., least squares) attribute weights. The equal weights method was also successfully applied in the construction literature (e.g. Mohamed, 2002; Imriyas *et al.* 2007a, 2007b, 2007c; Teo and Feng, 2010; Teo and Feng 2011). By using the equal weights method, a dimensionless quantity, Safety Culture Index (SCI), was developed to indicate the overall level of safety culture. SCI is derived by the following formula:

$$SCI = \frac{1}{10} \bullet \sum_{i=1}^{10} SC_i$$

where SC_i = Score of i^{th} indicator of safety culture (i=1, 2,…, 10).

The formula for calculating the individual scores is described below:

$$SC_i = \frac{1}{n_i} \bullet \sum_{j=1}^{n_i} A_{ij}$$

where n_i = number of scale items for i^{th} indicator; A_{ij} = j^{th} attribute score of i^{th} *indicator*.

4.3.1.5 Project hazard level

The level of project hazard was assessed by Project Hazard Index (PHI). The framework for estimating PHI developed by Imriyas *et al.* (2006) was adopted to develop the questionnaire for this study. As discussed in the literature review (see Section 2.3.3), there are eleven hazardous activities in this framework.

- *Hazard contributed by demolition works* (H_1). The level of hazard contributed by demolition works was deduced by three scale items. A sample item is '*Volume/size of demolition*'.

- *Hazard contributed by excavation works* (H_2). The level of hazard contributed by excavation works was deduced by five scale items. A sample item is '*Excavation configuration (depth, width and length)*'.

- *Hazard contributed by scaffolding and ladder use* (H_3). The level of hazard contributed by scaffolding and ladder use was deduced by three scale items. A sample item is ‘*Height of the scaffold/ladder that is to be used*’.

- *Hazard contributed by false works (H_4).* The level of hazard contributed by false works (temporary structure) was deduced by two scale items. A sample item is ‘*Volume of temporary structures involved in the project*’.

- *Hazard contributed by roof works (H_5).* The level of hazard contributed by roof works was deduced by two scale items. A sample item is ‘*Height of the roof*’.

- *Hazard contributed by erection works (H_6).* The level of hazard contributed by erection works was deduced by three scale items. A sample item is ‘*Height of erection work*’.

- *Hazard contributed by crane use (H_7).* The level of hazard contributed by crane use was deduced by four scale items. A sample item is ‘*Operating platform*’.

- *Hazard contributed by machinery and tools use (H_8).* The level of hazard contributed by machinery and tools use was deduced by five scale items. A sample item is ‘*Operating platform of plant and machinery (i.e. slope, etc.)*’.

- *Hazard contributed by works on contaminated sites (H_9).* The level of hazard contributed by works on contaminated sites was deduced by three scale items. A sample item is ‘*Duration of work on contaminated site*’.

- *Hazard contributed by welding and cutting works (H_{10}).* The level of hazard contributed by welding and cutting works was deduced by two scale items. A sample item is ‘*The volume of welding & cutting works’*.

- *Hazard contributed by works in confined spaces* (H_{11}). The level of hazard contributed by works in confined spaces was deduced by four scale items. A sample item is ‘*The volume of confined space works’*.

The eleven hazardous activities in building projects and their respective attributes for assessing each activity’s hazards were listed in the questionnaire (see Appendix 1). However, not every hazardous trade may be applicable to a given project. Thus, applicable trades need to be selected and rated. All the scale items in the questionnaire were anchored with the statement *‘Please rate the level of hazard posed by the following parameters in various works of this project. Please tick your responses below using the following scale: 1 = very low; 2 = low; 3 = ordinary level; 4 = high; and 5 = very high’*. Similar to the assessment of safety culture, there appears to be no prior knowledge regarding the weights of individual hazardous activities and scale items. Thus, the equal weights method (see section 4.3.1.4) was also applied to compute the overall scores of project hazard level. Then, the PHI was derived by the following formula:

$$PHI = \frac{1}{m} \bullet \sum_{i=1}^{11} H_i$$

Where: m is the number of applicable hazard activities; and $0<m\leq 11$.

The formula for calculating the individual scores is described below:

$$H_i = \frac{1}{n_i} \bullet \sum_{j=1}^{n_i} AS_{ij}$$

Where n_i = number of hazard attributes for i^{th} hazard activities; AS_{ij} = j^{th} hazard attribute score of i^{th} hazard activities.

4.3.1.6 Project characteristics

- *Project size.* Project size was measured by the contract sum of the project (quantitative factor);
- *Company size.* Company size was measured by the BCA grade of the company (quantitative factor);
- *Project type.* All the building projects are classified into 5 types, such as commercial building, residential building, office building, industrial building, and others (qualitative factor);
- *Complexity of project management.* The complexity of project management was measured by the percentage of work completed by subcontractors (in terms of contract value) (quantitative factor).

4.3.1.7 Data collection instrument

A data collection instrument was developed by defining and operationalizing the research variables (see Section 4.3.1). A sample data collection instrument is given in

Appendix 1. The instrument is divided into the following seven sections:

- ***Section A: Project and contractor information.*** In this section, interviewees were asked to provide the information about characteristics of the project and contractor, such as total man-hours, contract sum, project type, project duration, type of owner for the project, BCA Grade of the contractor, and so on.

- ***Section B: Safety performance.*** The objective of this section is to measure the safety performance of the project. Information about the number of fatal deceased workers, number of injured workers who are permanently disabled, number of injured workers who are temporarily disabled (with more than 3 days of medical care), number of minor injuries (with 3 or less medical care), and number of man-days lost due to accidents were collected in this section.

- ***Section C: Safety investments.*** This section aims to collect costs information about safety control activities in the project. The interviewees were required to review the historical records about the costs information of the 7 major safety investments components and their subcomponents or provide their estimation whenever there was no record available.

- ***Section D: Accident costs.*** This section aims to collect information about the costs incurred by the accidents. For the direct accident costs, the interviewees were required to review the historical record about the accidents occurred in the project, while, for the indirect accident costs, they were requested to review the documents if any, or provide their estimation based on the questions raised in this section. This section was designed for the filling of just one accident. For more than one accident, the interviewees were requested to photocopy this section for other accidents occurred in this project.

- ***Section E: Project hazard level.*** The objective of this section is to assess the level of physical hazard level of the project. The interviewees were required to rate the level of hazard posed by each of the attributes in various works of the project on a 5-point Likert-type scale between 1 = ‘very low’, 3 = ‘ordinary level’, and 5 = ‘very high’.

- ***Section F: Safety culture of the project.*** This section scrutinizes the safety culture level of the project by assessing each of the indicators of safety culture. Interviewees were required to indicate to what extent they agree or disagree with each of the statements found in this section based on the safety practices in this project on a 5-point Likert-type scale between 1 = ‘strongly disagree’, 3 = ‘neutral’, and 5 = ‘strongly agree’.

- ***Section G: Personal information.*** Questions such as the name of the interviewee(s) (optional), contact number, designation, and years of working experience in construction industry were set out in this section.

The selection of the 5-point scale with each scale point labeled is due to the following reasons: (1) odd numbered scale can provide a midpoint option which is required in this instrument to allow respondents to reflect a neutral position; while even numbered scales may affect outcomes by discriminating the answers into two distinctive categories, e.g. agree or disagree, and low or high, as there is no neutral option; (2) 5-point scale exhibits superior discrimination and reliability, and appears to produce more accurate than others. This is because, although 7-10 point scales may seem to gather more discriminating information, there is debate whether respondents actually discriminate carefully enough when filling out a questionnaire to make these scales valuable. Moreover, 2 and 3 point scales offer little discriminative value and cannot provide satisfactory data; and (3) defining each scale point instead of only anchoring the end points is used in this questionnaire as the former enables respondents to attach the same word to a numerical value, avoiding potential risks of misinterpretation of scale definitions by different respondents (Online materials, Pearson NCS, 2007; Li, 2007).

4.3.2 Data collection methods

After determining the type of research design and developing the data collection instrument, the next step in the research process is to select the appropriate data collection methods. Several methods can be used to collect primary data for non-experimental quantitative research, such as interviews, questionnaires and archives (Kumar, 2005; Tan, 2008; Fellows and Liu, 2008).

4.3.2.1 Interviews

Interviewing is a commonly used method of collecting information from people. It refers to any person-to-person interaction between two or more individuals with a specific purpose in mind (Kumar, 2005). According to the degree of flexibility, interviews can be: unstructured; semi-structured; and structured (Fellows and Liu, 2008). In unstructured interviews, the interviewer introduces the topic briefly and then records the replies of the respondent; whilst in structured interviews, the interviewer administers a questionnaire by asking questions and recording responses. Semi-structured interviews fill the spectrum between the two extremes. The strength of unstructured interviews is the almost complete freedom they provide in terms of content and structure. It is suitable for use in situations where either in-depth information is needed or little is known about the area. One major disadvantage of unstructured interview lies in the freedom of questions asked by interviewers and information obtained from interviewees, which can introduce investigator bias into the study. Another main weakness of using unstructured interviews is that the comparability of questions asked and responses obtained may become a problem. A main advantage of the structured interview, however, is that it provides uniform information, which assures the comparability of data. Also, structured interviewing requires fewer interviewing skills than does unstructured or semi-structured interview (Kumar, 2005).

4.3.2.2 Questionnaires

A questionnaire is a written list of questions, the answers to which are recorded by respondents (Kumar, 2005). Questionnaire may be administered by post/email/web to respondents, groups or particular individuals, or to individuals personally by the researcher (Fellows and Liu, 2008). ‘The only difference between an interview schedule and a questionnaire is that in the former it is the interviewer who asks the questions and records the respondent’s replies on an interview schedule, and in the latter replies are recorded by the respondents themselves’ (Kumar, 2005, p. 126). This distinction is important in accounting for the respective strengths and weaknesses of the two methods.

4.3.2.3 Archival records

Archival records are another useful source of data collection, often taking the form of computer files and records (Kumar, 2005). Examples of archival records include (Yin, 2009): public use files (e.g. census and other statistical data made available by government); service records (e.g. those showing the number of clients served over a given period of time); organisational records (e.g. budget and WSH records); personal records; maps and charts of the geographical characteristics of a place; and survey data (e.g. data previously collected about a site’s employees, residents, or participants). The strengths of archival data include: stable; unobtrusive; exact; broad coverage; and precise and usually quantitative (Yin, 2009). The major weakness of the archival data lies in the accessibility of such data due to privacy reasons. Unlike documentary evidence, Yin (2009) noted that the usefulness of these archival records will vary from case to case. For some studies, the records can be so important that they can become the object of extensive retrieval and quantitative analysis; while in other studies, they may be of only passing relevance (Yin, 2009). Yin (2009, p. 106) further stresses that '*most archival records were produced for a specific purpose and a specific audience other than the study, and these conditions must be fully appreciated in interpreting the usefulness and accuracy of the records'*.

4.3.2.4 Multiple sources of data

The choice of a method depends upon the purpose of the study, the type of data required, the resources available and the skills of the researcher. Yin (2009) noted that no single source has a complete advantage over all the others. The various sources are highly complementary, and a good study will therefore want to use as many sources as possible (Fellows and Liu 2008; Yin 2009). For this study, a combination of techniques, such as interviews, questionnaires and archival records was employed to collect information. As suggested by Eisenhardt (1989), it is hoped that the use of multiple sources of data collection will both strengthen the grounding of theory and also provide a synergistic perspective on evidence provided in this research.

The information about project and contractor characteristics (Section A of data collection instrument), project safety outcomes (Section B of data collection instrument), safety investments (Section C of data collection instrument) and accident costs (Section D of data collection instrument) was collected using structured interviews with accompanied by collection of archival data. Questionnaires were used to assess the project hazard level (Section E of data collection instrument) and safety culture level (Section F of data collection instrument). Some other documentation and archival records outside the interviewed projects were used to cross-verify the accuracy or trustworthiness of the data collected. The sources of such information may include various websites of the government (BCA, MOM), safety training providers (e.g., NTUC Learning Hub, BCA Academy, Singapore Contractors Associations, etc.), individual companies, WSH Council, Singapore Contractors Association, etc.

4.3.3 Sampling

Sampling is the process of selecting a sample from the sampling population to provide a practical means of enabling the data collection and processing components of research to be carried out whilst ensuring that the sample is representative (Fellows and Liu, 2008). The unit of analysis (see Section 4.2.3) implies that the target unit for sampling was the contractor project organisation. While organisations were sampled, the individuals in the contractor project teams were the ultimate target source of the information required. As there is no known population of the target organisations, a list of general building contractors who were registered with the Building Construction Authority (BCA) of Singapore was used as the start point to build a comprehensive sampling frame for this study. The contractors on BCA's list are those considered by BCA as having sufficient resources, experiences and technical expertise to undertake contracts of the nature and size defined by the BCA's registration heads and grades. The grades A1, A2, B1, B2, C1, C2, and C3 under Construction Work Heads CW 01 – General Building category are classified based on the tendering limit as shown in Table 4.2.

Table 4.2: Tendering Limits of General Building Contractors

	A1	A2	B1	B2	C1	C2	C3
Tendering Limit (S$ million) 1 Jul 09 to 31 Dec 09	unlimited	85.0	50.0	15.0	5.0	1.5	0.75
Tendering Limit (S$ million) 1 Jan 10 to 30 Jun 10	unlimited	85.0	40.0	13.0	4.0	1.3	0.65
Tendering Limit (S$ million) 1 Jul 10 to 30 Jun 11	unlimited	85.0	40.0	13.0	4.0	1.3	0.65

(Source: BCA, 2010)

In this study, 234 general building contractors belonging to the grades A1, A2, B1, and B2 under Construction Work Heads CW 01 – General Building category were selected for the data collection. The contractors belonging to the C1, C2, and C3 categories (with terdering limit of S$5 million and below) were excluded from the sampling frame of this study. It is because, according to practices of Singapore construction industry, small general building contractors (C1, C2, and C3) usually perform as sub-contractors of building projects and it is not possible to acquire complete information about the whole building project from sub-contractors (Teo and

Feng, 2010).

Since the sampling frame is naturally stratified by BCA Grade, stratified sampling method was adopted for this study. To ensure the representativeness, samples from homogeneous strata were randomly selected. In the first stage, 50 per cent of contractors under each BCA Grade were randomly selected from the sampling frame, and, in total, 117 building contractors were randomly selected from the sampling frame (see Table 4.3). Contact information of the selected contractors was collected mainly through personal contacts of the researcher, or by searching their websites if personal contacts with the contractors were unavailable. Good personal contacts with potential data providers tend to establish trust and confidence in the researcher, ease the data collection process and increase the response rate (Eriksson and Laan, 2007; Fellows and Liu, 2008). As noted by Fellows and Liu (2008, p. 29), '*trust and confidence are important considerations in data collection – the more sensitive the data, the more trust in the researcher which is required by the provider*'. All these randomly selected contractors were contacted via telephone or Email to request their participation in this study.

Table 4.3: Sample of Contractors Stratified by BCA Grade

BCA Grade	A1	A2	B1	B2	Total
Population	35	27	57	115	234
Sample (50%)	18	14	28	57	117

In the second stage, one to three projects from each contractor that was ready to participate in this study were selected as part of the sample based on the inclusion criteria. The criteria to select projects for this study include: (1) the projects should have been completed within the past three years; and (2) the safety personnel or the project managers of the projects, such as safety managers, safety officers or project managers, must be willing to participate in this study.

4.3.4 Determination of sample size

The major data analysis methods used in this study are multiple regression analysis and correlation analysis (see Section 4.4). The methods used to determine the sample size for multiple regression analysis are different from those used to determine the sample size for hypotheses tests because providing evidence that a parameter is not equal to some specific value is a fundamentally different task than accurately estimating the parameter (Algina and Olejnik, 2000). Maxwell (2000) argued that sample size would almost certainly have to be much larger for obtaining a useful prediction equation than for testing the statistical significance of the multiple correlation coefficients.

Miller and Kunce (1973) suggested that the minimal sample size to predictor ratio was 10 to 1 when using Multiple Linear Regression. Knofczynski and Mundfrom (2008) examined the methods to determine sample size when using Multiple Linear Regression for prediction. In Knofczynski and Mundfrom’s (2008) research, minimum sample sizes were determined based on the Squared Population Multiple Correlation Coefficients and the number of independent variables.

According to hypothesis 1 of this study (see Section 3.2), safety performance of building projects may be predicted by safety investments, safety culture and project hazard level. The maximum number of independent variables in hypothesis 1 was 3. Hypothesis 2 (see Section 3.3) postulates that the total accident costs of building projects may be predicted by accident frequency rate, project characteristics and project hazard level. The maximum number of independent variables in hypothesis 2 was also 3. Thus, the maximum number of independent variables in both hypotheses was estimated at 3 and the Squared Population Multiple Correlation Coefficients were estimated to be at medium level. According to the results of Knofczynski and Mundfrom's (2008) research, in order to derive a good prediction level, the recommended minimum sample size to predictor ratio was 13:1, i.e., the minimum sample size for this particular study was 39 (being 13 * 3). This sample size to predictor ratio is higher than the ratio of 10:1 suggested by Miller and Kunce (1973). Therefore, a sample size of 39 would be expected to yield reliable results.

4.3.5 Pilot study

Before conducting the interviews, a pilot study was conducted with the following purposes: (1) to test the reliability of the data collection instrument; (2) to assure that the wording and text of the questionnaire is clear and understandable; (3) to validate the content of constructs and measures and identify if something unique to Singapore's construction context was not considered in the data collection instrument; (4) to test the feasibility of data collection method; and (5) to obtain a reliable estimate of the anticipated completion time and valuable data collection experiences.

The data collection instruments were tested personally by the researcher so that the respondents can be observed and questioned if necessary. This pilot study was conducted by means of structured interviews using the initially designed data collection instrument. The interviewees comprised three project managers and two safety officers from five different completed building projects in Singapore. The three project managers had good personal contacts with the researcher, and they had recommended the other two interviewees based on the researcher’s requirement. The good personal contacts enabled trust and confidence to be established between the interviewees and the researcher, by which the researcher may obtain more reliable feedback from the interviewees. All the three project managers have more than 15 years of experience in construction industry, and both the two safety officers are registered Workplace Safety and Health Officers (WSHO) with MOM and have more than 10 years of experience in construction safety. This indicates that all the interviewees have adequate recognition and knowledge of WSH issues in Singapore’s construction context.

The pilot study was divided into two phases. In the first phase, a softcopy of the initially designed instrument was sent via Email to the three interviewees that had good personal contacts with the researcher. They were required to go through the instrument carefully and provide their comments regarding the following questions: (1) are the wordings and organisations of questions clear and understandable? (2) are the items, measures, indicators and statements compatible with Singapore’s construction context? (3) are there any other potential questions that are unique to Singapore’s construction context to be added to the instrument? (4) are all the information required in the instrument available for your project? and (5) are there any other comments on the instrument?

Based on the feedback from the three respondents, some changes were made to the initially designed instrument: (1) some wordings of the instrument were changed to avoid confusion; (2) total number of injured workers was further categorized as number of fatal deceased workers, number of injured workers who are permanently disabled, number of injured workers who are temporarily disabled (more than 3 days of medical care), and number of minor injuries (i.e., three or less days lost); (3) the types of compulsory formal training courses were amended; (4) the compensations to the injured workers was further categorized into compensations covered by insurance policy and those not covered by insurance policy due to the underreporting issue in some of Singapore’s construction firms; and (5) a question about language barriers was added to the safety culture assessment form under the dimension of supportive environment to reflect the multi-language working environment in Singapore’s construction sites.

In the second phase, five structured interviews were conducted using the revised instrument. During each interview session, the interviewee was requested to answer all questions in the instrument and rate the attributes in the project hazard and safety culture assessment forms (Sections E and F). The results of the interviews show that all the information required in the instrument can be obtained through interviews and checking the archival records of the project. The wordings and text of the instrument were further checked during the five structured interviews. Two further amendments were made to the instrument: (1) to reflect the true cost of safety staffing, a question about the percentage of time spent on safety work was added to the instrument; and (2) the costs of safety facilities were further categorized into material/equipment cost and manpower cost. Also, a reliable estimate of the anticipated completion time (roughly 2 hours), and, more importantly, valuable experiences were obtained to enable subsequent interviews to be conducted more effectively and efficiently.

4.3.6 Data collection procedure

Before the interviews and questionnaires were carried out, a key contact person for each target project was recommended by the contractor. This key contact person served as the link between the researcher and the potential sources of information or questionnaire respondents. The key contact person also enabled possible follow-ups if there was any unclear or missing information. In this context, typical targets as key contact persons included project managers/directors and project safety managers/officers. The next step was to conduct face-to-face interviews upon being granted the opportunity to interview the project managers/directors or safety managers/officers. Project managers/directors are the first choice of interviewees as they have deeper and broader understanding of the projects' WSH strategies and performance. Also, they are the most likely persons to get access to the archival records of the projects. The second choice is the project safety managers/officers, who are in charge of the WSH issues of the projects.

The interviewees were requested to recall or review the archival records of the project, or provide their estimation whenever the records were unavailable to complete Section A (project and contractor information), B (safety performance), C (safety investments) and D (accident costs) of the data collection instrument. In general, the face-to-face project interviews took 1.5 to 2.5 hours to conduct depending on the number of accidents occurred in the project and the availability of records of the information. During the interview, the interviewees were requested to show the evidence or records of the information to be collected. Such evidence include: WSH statistics of the company and project; safety inspection records; safety audit report; project WSH plan; company and project organisational chart; insurance policy document; project master schedule; internal safety management systems; safety training records; name cards; company brochures; etc.

In most cases, the project manager/director or safety manager/officer did not answer all the questions by himself/herself. He/she had to consult other project personnel such as quantity surveyors and safety supervisors, or the personnel in the head office who was in charge of WSH issues during the interview. Archival records, usually in the form of computer records, were also checked to ensure the accuracy of information. Sometimes, the interviewer did not obtain all the answers of the interview questions during the interview session due to the tight schedule of the interviewees or the unavailability of some data. In such situation, a follow-up face-to-face interview or telephone interview was scheduled to obtain the answers of all the interview questions. Upon completion of each interview session, the interviewees were provided with a copy of the recorded answers, and were requested to review and confirm the answers and also give their feedback on their answers (if any) via Email. This is to provide a chance to cross-verify the accuracy of the data collected with the respondents.

For each of the interviewed projects, in order to enhance the data validity, three members of site management staff, such as project managers/directors, construction/site managers, site engineers, safety managers/officers, and safety supervisors were requested to complete the Section E (project hazard level) and F (safety culture of the project) of the data collection instrument. The questionnaires were directly handed over to the three respondents, who were requested to fill out Sections E and F before eyes. The averages of PHI value and SCI value derived from the three questionnaires were used to gauge the project hazard level and safety culture level respectively. The sample size of three observers is considered adequate for providing valid assessment of project hazard level and project safety culture level, following the triangulation of observers, which presents that information about a single phenomenon should be collected from at least three different observers (Hamersley and Atkinson, 1983; Neuman, 2005).

In order to encourage the potential respondents to participate in this study, some measures were also taken during the data collection process: (1) ensuring that providers of data cannot be traced from the output of the research by not requiring them to provide their names and addresses (anonymity); (2) confidentiality was assured verbally and confirmed in writing in the formal letter of invitation for participation, which contains an explanation of the research, the purpose of work, type of information required, etc. and (3) promising that outcomes of the research will be shared with the data providers.

To further check the accuracy or trustworthiness of the data collected, some additional measures were taken:

- Reviewing the WSH regulations, WSH annual reports and WSH statistics published in the website of MOM and WSH Council of Singapore. These regulations and statistics may provide a good indication of the basic safety requirements and overall level of safety performance by industry.

- Reviewing the various lists of past WSH Awards/Competitions winners published in the websites of the Singapore Contractors Association Ltd. and WSH Council.

- Reviewing the list of contractors with Demerit Points, the list of factories and work-sites issued with Stop Work Orders and the list of offenders convicted under WSHA, which were published in the Website of MOM. This information was used to check those cases which reported poor safety performance, Stop Work Orders, and fines.

- Reviewing the statistical information of labour market that was published in the MOM website. Such information include average wages/salaries by industry, hours worked and percentage of foreign workers.

- Inspecting the websites of major safety courses providers (e.g., NTUC Learning Hub, BCA Academy, Singapore Contractors Associations, etc.) in Singapore to check the rates of various formal safety training courses.

- Searching the websites of the interviewed companies for relevant information, such as safety and health performance, corporate culture, company size and business scope, organisational chart, major projects, etc.

- Conducting informal conversations with the workers or staff of the interviewed projects and the industrial practitioners with whom the researcher has good contact.

The information obtained through the above ways was used to compare with the data collected through the interviews and archival records to identify the abnormal data or cases before they were processed and analysed.

4.3.7 Validity and reliability issues

4.3.7.1 Validity and reliability of data collection instrument

Validity and reliability are the main issues concerning all the academic research. Without adequately taking into account the validity and reliability of the data collection instrument, no matter how scientific and robust data analysis methods are used, the results and conclusions would be questionable. In terms of measurement procedures, '*Validity is defined as the degree to which the researcher has measured what he has set out to measure*' (Smith 1991, p.106). There are three common types of validity: face and content validity, concurrent and predictive validity, and construct validity (Kumar, 2005). Face and contend validity refers to the degree to which the instrument reflects a specific domain of the content. Specifically, face validity is the establishment of a logical link between each question or item on the scale and an objective; whilst content validity refers to how well the items and questions cover the full range of the issue or attitude being measured. One of the main advantages of face and contend validity is that it is easy to apply. Concurrent and predictive validity Predictive validity is judged by the degree to which an instrument can forecast an outcome. Concurrent validity is judged by how well an instrument compares with a second assessment concurrently done. Construct validity is determined by ascertaining the contribution of each construct to the total variance observed in a phenomenon. It is based on statistical procedures. In the research design and data collection stage, the validity of the research instrument is assured by taking the following precautions:

- The instrument used to assess project hazard level and safety culture level in this study has gained its adequate content validity with solid theoretical support, as the design and selection of measurement items are based on an extensive literature review. Each construct of safety culture and project hazard was measured by at least two scale items, which follows the principle of triangulation. The items for measuring the costs of accident prevention activities, direct costs of accidents and indirect costs of accidents were also derived from an extensive literature review, in which these items have been judged to be valid with adequate theoretical supports (refer to Section 4.3.1 for details).

- In addition to theoretical support mentioned above, a pilot study was carried out to pre-test the data collection instrument. An initially-designed instrument was tested during the pilot study. The comments from the five interviewees add content validity to the instrument in the context of Singapore’s building construction industry through adding and revising items that were pertinent to Singapore context and deleting those that did not fit Singapore context. This is to assure that the content of each construct captures all the domains of the construct and is well represented by the measurement items employed.

Reliability refers to the degree of consistency and stability in an instrument. '*A scale or test is reliable to the extent that repeat measurements made by it under constant conditions will give the same result*' (Moser and kalton, 1989, p.353). As noted by Kumar (2005, p.157), in the social sciences, however, '*it is impossible to have a research tool which is 100 per cent accurate, not only because a research instrument cannot be so but also because it is impossible to control the factors affecting reliability*'. These factors may include the following: (1) the wordings of questions; (2) the physical setting; (3) the respondent's mood; (4) the nature of interaction; and (5) the regression effect of an instrument. Most of these factors are uncontrollable actions of the respondents, which are beyond the control of the study. In this regard, some precautions, such as pre-testing the instrument in the pilot study, asking the respondents to fill out the questionnaire in front of the researcher's eyes, etc. were carried out to mitigate the potential threats of these factors and establish the reliability of the instrument.

Furthermore, the validity and reliability of the data collection instrument and methods were also well established in the form of publications of research papers, which are subjected to peer review. Peer review provides an opportunity for independent judges to question various aspects of the research, e.g. arguments, methodology, methods, interpretations and conclusions (Xiao, 2002). So far, a refereed conference paper and three refereed journal papers which were related to this research and used the data collection instrument developed for this research have been published. The acceptance of these papers for publication after going through a rigorous peer review process provides a strong indication that the data collection instrument and data collection methods are valid and reliable.

4.3.7.2 Potential threats to the validity of research

Although it is difficult to eliminate or control all potential threats to the validity of the study (e.g., some uncontrollable actions of respondents were beyond the control of the study), this study adopted a proactive attitude to first identify the potential threats of bias, and then carry out precautions to mitigate them as far as possible throughout the research lifecycle. The following potential threats in the research design and data collection stage are identified and dealt with:

- *Accuracy/trustworthiness of data collected.* To ensure the accuracy of the data collected and maintain the integrity of research, the following precautions were adopted: (1) careful selection of appropriate respondents (i.e., only project managers/directors and project safety managers/officers were selected as the key contact persons/interviewees of each selected project); (2) data sources triangulation (e.g., structured interviews, company website, company brochures, computer records, government website, informal conversations, insurance policy documents, internal safety management systems documentation, internal safety inspections records, safety audit records, etc.); (3) assessors triangulation (i.e., three respondents were requested to assess the level of safety culture and project hazard); (4) adequate transparency (i.e., this research has provided adequate transparency for potential replication to enhance the reliability of the results); and (5) Respondent cross-verification of the data (i.e., after the completion of each interview session, the interviewees were requested to review and confirm the answers and also give feedback (if any) on the data collection).

- *Errors by the respondents or interviewees* (e.g., forgetting, seriousness, embarrassment, misunderstanding, or lying) (Neuman, 2003). Although this type of threats is largely beyond the control of the research, they were mitigated by carrying out the following precautions: (1) allowing anonymity; (2) ensuring confidentiality; (3) ensuring clarity of questions through pilot study; (4) asking respondents to complete the questionnaire in front of the researcher's eyes; (5) using multiple respondents (i.e., three observers were requested to complete Sections E and F of the data collection instrument); and (6) cross-checking the accuracy of the data collected using multiple sources (i.e., the accuracy of the data collected via interviewers' recollection were checked by reviewing relevant archival data).

- *Unintentional errors or sloppiness of the interviewer* (e.g., contacting the wrong respondent, misreading a question, omitting questions, reading questions in the wrong order, recording the wrong answer to a question, or misunderstanding the respondent) (Neuman, 2003). The precautions to mitigate the influence of this type of bias include: (1) obtaining enough interview experiences by conducting pilot studies to enable the subsequent interviews to be smoothly conducted; (2) allowing the interviewees to have a copy of the interview questions during the interviews; and (3) requesting the interviewees to cross check the recorded answers.

- *Intentional subversion by the interviewer* (e.g., purposeful alteration of answers, omission or rewording of questions, or choice of an alternative respondent) (Neuman, 2003). This type of potential errors was strictly eliminated by conducting all the interviews personally by the researcher in this research. No other interviewers were employed in this research.

- *Influence on the answer due to the long duration of the interviews*. To mitigate this threat, the following 3 measures were undertaken: (1) a substantial amount of careful pre-planning was undertaken to ensure the smoothness of the whole process of interviews; (2) a suitable time for interview was scheduled to allow enough time to complete the interview questions; and (3) a follow-up interview was scheduled once the interview questions were not completed in one session due to the tight schedule of the interviewees or the availability of information.

4.4 Data analysis methods

4.4.1 Correlation analysis

Correlation refers to the relationship between two continuous variables (co-relationships) (McQueen and Knussen, 2006). The relationship between two variables can be measured using a correlation coefficient. There are many types of correlation coefficients, among which the Pearson correlation coefficient (*r*) is perhaps the one most commonly used in management research (Tharenou *et al.*, 2007). Pearson correlation coefficient can be used to measure the direction and strength of the linear relationship between continuous variables (Kline, 2005). The Pearson correlation coefficient ranges from -1 through 0 to 1, where 1 represents a perfect positive linear association, 0 represents no linear association, and -1 represents a perfect negative linear association. The direction of the correlation is positive when both variables increase together, but it is negative when one variable increases as the other decreases. Weak relationship will be indicated by values closer to zero.

Bivariate correlation analysis can be used to answer simple research questions/hypotheses concerning two variables. However, it cannot be used to answer more complex research questions/hypotheses, such as the non-linear relationship between two variables, the mediation and moderation effects, and the relationships among three or more variables. Regression analyses are required for these purposes and discussed in the subsequent sections.

4.4.2 Regression analysis

Regression analysis is a statistical technique for investigating and modeling the relationship between variables (Montgomery *et al.*, 2006). It is one of the most widely used techniques for analyzing multifactor data (Montgomery *et al.*, 2006). Regression modeling, either in linear forms or in more sophisticated forms (such as nonlinear), has been widely used as a tool to interpret and change a set of data into the forms of information that can be used for several purposes, from simple statistical inferences to complex prediction models (Lu, 2005; Montgomery *et al.*, 2006).

4.4.2.1 Regression modelling

Simple linear regression is a model with a single independent variable x that has a relationship with an independent variable y that is a straight line. This simple linear regression model is given in Eq. 4.1.

$$y = \beta_0 + \beta_1 \bullet x + \varepsilon \quad \text{………………………………………………………………..……} (Eq.\ 4.1)$$

Where the intercept β_0 and the slope β_1 are unknown constants and ε is a random error component.

Multiple regression is employed when there are more than one independent variables. It uses several independent variables (x_1, x_2, …, x_n), called the predictor variables, to assess the extent of their relationship simultaneously with a single dependent variable (y), the criterion variable (Tharenou *et al.*, 2007). The multiple regression model is given in Eq. 4.2.

$$y = \beta_0 + \beta_1 \bullet x_1 + \beta_2 \bullet x_2 + \ldots + \beta_n \bullet x_n + \varepsilon \quad \text{………………………………………} (Eq.\ 4.2)$$

Where the intercept β_0 and the slopes (β_1, β_2 ,…, β_n) are unknown constants and ε is a random error component.

The well-known least square was used to derive the regression parameters for the initial models (Jia, 2006). The main reason for the popularity of the ordinary least squares could be explained through its easy calculation (low computational costs and its intuitive plausibility) in most cases (Jia, 2006). The statistical theory which is used to develop the least square model has been well-developed and provides useful guidelines to interpret the results of regression analysis. There are several methods such as the *t*-test, the *F*-test, and the prediction intervals developed to evaluate and examine the accuracy of the models (Jia, 2006).

The assumptions underlying regression analysis need to be tested. This is because the complexity of the relationships, owing to the typical use of a large number of variables, makes the potential distortions and biases more potent when the assumptions are violated (Hair *et al.*, 1998). Hair *et al.* (1998) suggest that the researcher must be aware of any assumption violations and the implications they may have for the estimation process or the interpretation of the results. Analysis to ensure that the research is meeting the basic assumptions of multiple regression analysis involves two steps: (1) testing the individual dependent and independent variables, and (2) testing the overall relationship after model estimation.

In the initial stage, the three assumptions to be addressed for the individual variables are linearity, constant variance, and normality (Hair *et al.*, 1998; Witte and Witte, 2007). Firstly, in the tests of linearity, Witte and Witte (2007) suggests that research needs to worry about violating the assumption of linearity only ‘when the scatterplot for the original correlation analysis reveals an obviously bent or curvilinear dot cluster’ (p. 164). Secondly, the assumption of constant variance states that the dots in the original scatterplot will be dispersed equally about all segments of the regression line. Witte and Witte (2007) notes that researcher needs to worry about violating this assumption ‘only when the scatterplot reveals a dramatically different type of dot cluster’ (p. 164). Finally, perhaps the most frequently encountered assumption violation is nonnormality of the independent or dependent variables or both (Hair *et al.*, 1998). Hair *et al.* (1998) further suggests that the original variables may be preferred for the comparability in the interpretation phase as regression analysis has been shown to be quite robust even when the normality assumption is violated.

In the stage of evaluating the estimated equation, the assumptions to be examined are linearity, homoscedasticity, independence of the residuals, and normality of residuals (Hair *et al.*, 1998). The first assumption, linearity, will be assessed through an analysis of residuals and partial regression plots. If no apparent nonlinear pattern is exhibited, the assumption of linearity is deemed to be met. The next assumption deals with the constancy of the residuals across values of the independent variables, which can be tested through examination of the residuals plots. The third assumption deals with the effect of carryover from one observation to another, thus making the residual not independent. Again, the residuals can be plotted to see whether a pattern emerges. The final assumption is normality of the error term of the variate with a visual examination of the normal probability plots of the residuals. If the values fall along the diagonal with no substantial or systematic departures, the residuals are considered to represent a normal distribution (Hair *et al.*, 1998).

4.4.2.2 Determination of functional form

As the relationship between the dependent variable and independent variable may not always be linear, the functional form for their relationship needs to be determined (or approximated) through a limited amount of experimentations. According to Crown (1998), a common approach is to estimate linear, log-log (for double log), and exponential versions of the model and then to choose the "best" one. This approach was also used in this study to choose among the alternative model specifications.

- Basic linear functional form

Firstly, consider the basic linear equation (Eq. 4.3) specifying the relationship between the dependent variable (*y*) and the independent variable (*x*) in a population:

$$y = \beta_0 + \beta_1 \bullet x + \varepsilon \quad \text{...(Eq. 4.3)}$$

Where the population intercept β_0 and the population slope β_1 are unknown constants and ε is a random error component in the population.

Based on the hypotheses developed in Chapter 3, it is possible that the relationship between the dependent variable (*y*) and the independent variable (*x*) is affected by other variables ($m_1, m_2 \ldots m_n$). This implies that both the population intercept β_0 and the population slope β_1 are likely to be dependent on the value of other variables ($m_1, m_2 \ldots m_n$). Thus,

$$\beta_0 = \alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n \text{ ………………………………. (Eq. 4.4)}$$

$$\beta_1 = \gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n \text{ …………………………………….. (Eq. 4.5)}$$

where $m_1, m_2 \ldots m_n$ represent the variables influencing the relationship between the dependent variable (y) and the independent variable (x), the intercepts (α_0 and γ_0) and the slopes ($\alpha_1, \alpha_2, \ldots, \alpha_n$) and ($\gamma_1, \gamma_2, \ldots, \gamma_n$) are unknown constants.

Eq. 4.3, Eq. 4.4, and Eq. 4.5 can be combined by substituting ($\alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n$) for β_0 and ($\gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n$) for β_1, then

$$y = (\alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n) + (\gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n) \bullet x + \varepsilon$$

$$= \alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n + \gamma_0 \bullet x + \gamma_1 \bullet m_1 \bullet x + \gamma_2 \bullet m_2 \bullet x + \ldots + \gamma_n \bullet m_n \bullet x + \varepsilon$$

$$\text{………………………………………………………………………….…… (Eq. 4.6)}$$

Eq. 4.6 is the linear model for the relationship between the dependent variable (y) and the independent variable (x).

- Log-log functional form

Secondly, the log-log functional form was considered. The basic relationship between the dependent variable (y) and the independent variable (x) was posited as Eq. 4.7.

$$y = e^{\beta_0} \bullet x^{\beta_1} \bullet e^{\varepsilon} \quad \text{……………………………….……………………… (Eq. 4.7)}$$

Taking the natural logarithm of both sides yields the linear estimating equation:

$$\ln y = \beta_0 + \beta_1 \bullet \ln x + \varepsilon \quad \text{…………………………...……………………. (Eq. 4.8)}$$

Where the population intercept β_0 and the population slope β_1 are unknown constants and ε is a random error component in the population.

Based on the hypotheses developed in Chapter 3, it is possible that the relationship between the dependent variable (y) and the independent variable (x) is affected by other variables (m_1, m_2… m_n). This implies that both the population intercept β_0 and the population slope β_1 are likely to be dependent on the value of other variables (m_1, m_2… m_n). Thus,

$$\beta_0 = \alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n \quad \text{…………………………….….. (Eq. 4.9)}$$

$$\beta_1 = \gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n \quad \text{…………………………….…….. (Eq. 4.10)}$$

where m_1, m_2… m_n represent the variables influencing the relationship between the dependent variable (y) and the independent variable (x), the intercepts (α_0 and γ_0) and the slopes (α_1, α_2,…, α_n) and (γ_1, γ_2,…, γ_n) are unknown constants.

Eq. 4.8, Eq. 4.9, and Eq. 4.10 can be combined by substituting ($\alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n$) for β_0 and ($\gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n$) for β_1, then

$$\ln y = (\alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n) + (\gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n) \bullet \ln x + \varepsilon$$

$$= \alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n + \gamma_0 \bullet \ln x + \gamma_1 \bullet m_1 \bullet \ln x + \gamma_2 \bullet m_2 \bullet \ln x + \ldots + \gamma_n \bullet m_n \bullet \ln x + \varepsilon \quad \text{(Eq. 4.11)}$$

Eq. 4.11 is the log-log model for the relationship between the dependent variable (y) and the independent variable (x).

- Exponential function form

Finally, the exponential functional form was considered. The basic relationship between the dependent variable (y) and the independent variable (x) was posited as Eq. 4.12.

$$y = e^{\beta_0} \bullet e^{\beta_1 \bullet x} \bullet e^{\varepsilon} \quad \text{(Eq. 4.12)}$$

Taking the natural logarithm of both sides yields the linear estimating equation:

$$\ln y = \beta_0 + \beta_1 \bullet x + \varepsilon \quad \text{(Eq. 4.13)}$$

Where the population intercept β_0 and the population slope β_1 are unknown constants and ε is a random error component in the population.

Based on the hypotheses developed in Chapter 3, it is possible that the relationship between the dependent variable (y) and the independent variable (x) is affected by other variables ($m_1, m_2 \ldots m_n$). This implies that both the population intercept β_0 and the population slope β_1 are likely to be dependent on the value of other variables ($m_1, m_2 \ldots m_n$). Thus,

$$\beta_0 = \alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 4.14)}$$

$$\beta_1 = \gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 4.15)}$$

where $m_1, m_2 \ldots m_n$ represent the variables influencing the relationship between the dependent variable (y) and the independent variable (x), the intercepts (α_0 and γ_0) and the slopes ($\alpha_1, \alpha_2, \ldots, \alpha_n$) and ($\gamma_1, \gamma_2, \ldots, \gamma_n$) are unknown constants.

Eq. 4.13, Eq. 4.14, and Eq. 4.15 can be combined by substituting ($\alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n$) for β_0 and ($\gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n$) for β_1, then

$$\begin{aligned} \ln y &= (\alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n) + (\gamma_0 + \gamma_1 \bullet m_1 + \gamma_2 \bullet m_2 + \ldots + \gamma_n \bullet m_n) \bullet x + \varepsilon \\ &= \alpha_0 + \alpha_1 \bullet m_1 + \alpha_2 \bullet m_2 + \ldots + \alpha_n \bullet m_n + \gamma_0 \bullet x + \gamma_1 \bullet m_1 \bullet x + \gamma_2 \bullet m_2 \bullet x + \ldots \\ &\quad + \gamma_n \bullet m_n \bullet x + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 4.16)} \end{aligned}$$

Eq. 4.16 is the exponential model for the relationship between the dependent variable (y) and the independent variable (x).

As suggested by Jaccard *et al.* (1990), to overcome the threat of multicollinearity in interactive models and facilitate the explanations of the regression coefficients, x, y, and (m_1, m_2… m_n) need to be centered (prior to forming the multiplicative term) by subtracting the mean variable value from each score of the variables. Such an additive transformation will tend to yield low correlations between the product term and the component parts of the term (Jaccard *et al.*, 1990).

To choose the appropriate functional form among the alternative model specifications, several criteria were suggested by Crown (1998). The first criterion is whether the models have statistically significant coefficients with the expected signs as suggested by theories. The second criterion is how well each of the models satisfies the assumptions underlying the regression model. This is because the complexity of the relationships makes the potential distortions and bias more potent when the assumptions are violated. For example, models with normal (or nearly normal) error distributions are preferred to those whose error distributions are not normal, everything else being equal. The third criterion is how well the functional form fits the underlying theories. The fourth criterion is that it is generally best to choose the model that requires the fewest additional assumptions. In addition, it is tempting to also use the adjusted R^2 of the different models as a basis for comparison. Higher R^2 means more of the variation in the dependent variable is explained by the independent variables. The model with higher adjusted R^2 is always preferred than those with lower adjusted R^2. However, the comparison of the adjusted R^2 of the different models must be used with caution if the dependent variables of the models are inconsistent with one another.

4.4.3 Moderation analysis

In this study, it was hypothesized that the relationship between the level of safety investments and safety performance is affected by the level of safety culture and project hazard level (see Section 3.2). To test whether a third variable affects the relationship between the dependent and independent variables, moderated regression analysis can be used (Tharenou *et al.*, 2007).

A moderator is a variable that affects the direction and or strength of the relation between an independent or predictor variable and a dependent variable (Baron and Kenny, 1986; Tabachnick and Fidell, 2000). The moderators interact with the independent variables to predict the dependent variable (Tharenou *et al.*, 2007). The moderated effect (or interaction effect) of two independent variables in determining a dependent variable is said to occur when the partial effect of one depends on the value of the other (Fox, 1997).

Tharenou *et al.* (2007) summarized the process of conducting moderated regression analysis. The first step is to calculate the interaction term between the independent variable and the moderator variable by multiplying the two variables together. This is called a product term and represents the interaction effect. To avoid multicollinearity, the independent and moderator variables need to be transformed by either centering or converting them to standardized (z) scores (z-scores are by definition centered). By multiplying the two (centered or standardized) scores together, it is possible to determine whether their systematic variation is related to the change in the dependent variable. An interaction (moderator) effect is indicated if the product term is statistically significant, with the independent and moderator variables also included in the equation.

The moderator model (see Baron and Kenny, 1986) is described in Figure 4.2. There are three paths leading to the dependent variable: the impact of the independent variable (x) on the dependent variable (y) (path a); the impact of the moderator variable (m) on the dependent variable (y) (path b); and the impact of the interaction of the independent variable and the moderator variable ($x \bullet m$) on the dependent variable (y) (path c). The regression model postulates that y is a linear function of x, m and the interaction of x and m ($x \bullet m$) (Eq. 4.17).

$$y = \beta_0 + \beta_1 \bullet x + \beta_2 . m + \beta_3 . x \bullet m + \varepsilon \quad \text{……………………………………… (Eq. 4.17)}$$

Where the intercept β_0 and the slopes (β_1, β_2 , β_3) are unknown constants and ε is a random error component.

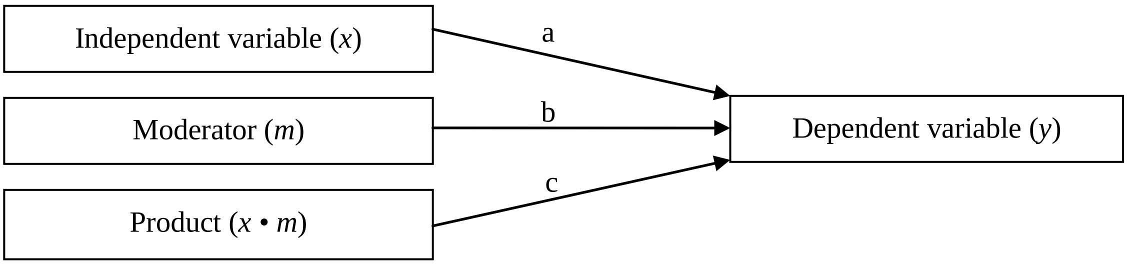


Figure 4.2: The Moderated Regression Model (source: Baron and Kenny, 1986)

Aiken and West (1991) and Cohen *et al.* (2003) suggested that, to facilitate the interpretation the moderation effects (interaction effects), the regression of *y* on *x* can be plotted on three values of *m*: the mean value of *m*; a low value of *m*; and a high value of *m*. Cohen *et al.* (2003) recommend a convenient set of values to choose: the mean of *m* (m_{mean}), one standard deviation below the mean of *m* (m_{low}), and one standard deviation above the mean of *m* (m_{high}). Thus, three simple regression lines for *y* on *x* at three values of *m* can be plotted and compared with each other.

4.4.4 Mediation analysis

The purpose of mediation analysis is to examine whether an independent variable leads to another variable (the mediator), which then transmits the effects of the independent variable to the dependent variable (Baron and Kenny, 1986). A variable may be said to function as a mediator to the extent that it accounts for the relation between the predictor and the criterion (Baron and kenny, 1986). The mediator is an intervening variable between a predictor and an outcome or dependent variable (Woodworth, 1928). Mediator variable explains *how* effects of a variable on another variable occur (Tharenou *et al.*, 2007). An example of the use of mediation analysis in the context of construction is presented by Lingard and Francis (2005), who tested whether work–family conflict mediated the relationship between job stressors and burnout among male construction professionals, managers and administrators.

There are two types of mediation, namely complete mediation and partial mediation. In complete mediation, the independent variable affects the dependent variable only indirectly through the mediator, whereas in partial mediation the independent variable has both a direct effect on the dependent variable and an indirect effect on the dependent variable, the latter being transmitted by the mediator (James and Brett, 1984). Partial mediation indicates that only part of the total effect of the independent variable on the dependent variable is due to mediation by the mediator.

The mediation model (see Baron and Kenny, 1986) is presented in Figure 4.3. According to Tharenou *et al.* (2007), the most common way for testing mediation is to use multiple regression. As suggested by Baron and Kenny (1986), three steps need to be carried out to test the mediation effect using regression methods.

- ***Step 1:*** Regress the mediator on the dependent variable (Figure 4.3, path a), because they need to be related (statistically significant) if the mediator really does mediate the independent variable.

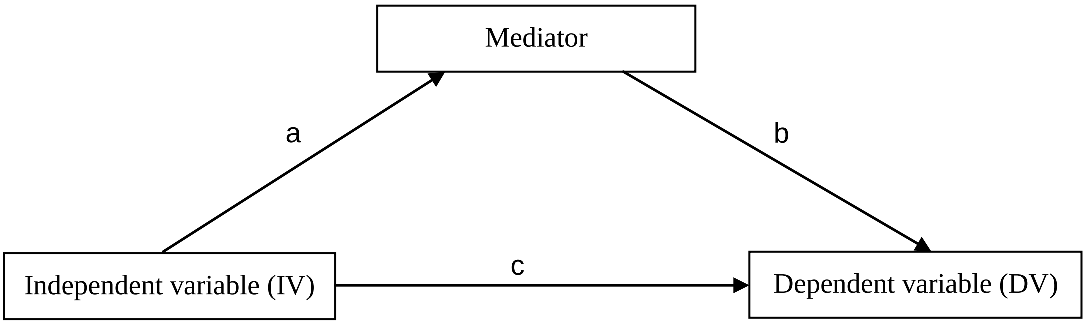


Figure 4.3: The Mediation Model (Source: Baron and Kenny, 1986)

- ***Step 2:*** Regress the dependent variable on the independent variable (Figure 4.3, path c), because they need to be related (statistically significant) if the independent variable could have its influence mediated by another variable.

- ***Step 3:*** Add the mediator to this last equation (Figure 4.3, path b). To test this, run a regression analysis with both the independent variable and the mediator predicting the dependent variable. If the mediator completely transmits the effect of the independent variable on the dependent variable, the regression coefficient for the independent variable now is no longer statistically significant, because all of its effect is removed by going through the mediator variable. It is possible to have a partial mediator effect, where the regression coefficient for the independent variable goes down in magnitude, but is still statistically significant (James and Brett, 1984; as cited by Tharenou *et al.*, 2007).

In summary, mediation can be said to occur when: (1) the IV significantly affects the mediator; (2) the IV significantly affects the DV in the absence of the mediator; (3) the mediator has a significant unique effect on the DV; and (4) the effect of the IV on the DV shrinks upon the addition of the mediator to the model (Baron and Kenny, 1986).

The amount of mediation, which is called the indirect effect, is defined as the reduction of the effect of the independent variable on the dependent variable. To determine the significance of the indirect effect, the Sobel test first proposed by Sobel (1982) was highly recommended (MacKinnon *et al.*, 2002). The formula for the Sobel test was drawn from MacKinnon and Dwyer (1993) and described as below (Eq. 4.18):

$$Z_{\text{-value}} = a \bullet b \,/\, \text{SQRT}\,(b^2 \bullet s_{a2} + a^2 \bullet s_{b2}) \qquad \text{(Eq. 4.18)}$$

where a = raw (unstandardized) regression coefficient for the association between independent variable and mediator;

s_a = standard error of a;

b = raw coefficient for the association between the mediator and the dependent variable (when the independent variable is also a predictor of the dependent variable); and

s_b = standard error of b.

4.4.5 Validation methods of regression model

Before a regression model is used, Snee (1977) suggested that some assessment of its validity should be made. Model validation aims to determine if the model will function successfully in its intended operating environment (Montgomery *et al.*, 2006).

According to Montgomery *et al.* (2006) and Fox (1997), an effective method of validating a regression model with respect to its prediction performance is to set aside some of the original data and use these observations to investigate the model's predictive performance, which is called data splitting (Snee, 1977; Montgomery *et al.*, 2006) or cross-validation (Stone, 1974; Fox, 1997). Data splitting /cross-validation simulates the collection of new data by randomly dividing the original data into two parts – the first part to be used for model formulation and the second for model validation, which are also called estimation data and prediction data by Snee (1977). In a typical cross-validation, the estimation data and prediction data must cross-over in successive rounds such that each data point has a chance of being validated against (Michaelsen, 1987; Montgomery *et al.*, 2006).

Cross-validation may be done in several ways, e.g., *k*-fold cross-validation, leave-one-out cross-validation, and repeated *k*-fold cross-validation (Kohavi, 1995). Michaelsen (1987) recommended the leave-one-out cross-validation, which is equivalent to the predicted-residual-sum-of-squares *(PRESS)* procedure as described by some researchers (e.g. Weisberg, 1985; Montgomery *et al.*, 2006; Snee, 1977) as the best method for a smaller number of observations. Leave-one-out cross-validation (LOOCV) or *PRESS* procedure uses a special form of data splitting to obtain a measure of model prediction accuracy. Each observation is left out at a time and predicted by a model developed from the remaining (n-1) observations. In this way, the model is developed on a dataset that has almost as many degrees of freedom as the original and independent predictions are made for each data point (Michaelsen, 1987). The predictive performance estimation obtained using LOOCV or PRESS procedure is known to be almost unbiased (Efron, 1983), and therefore it was used in this study to validate the regression models. The procedures for conducting LOOCV are given below.

a) Omit an observation (y_i) and develop the model from the remaining 46 observations;

b) Use the model developed from (a) to predict the omitted observation ($\hat{y}_{(i)}$);

c) Repeat steps (a) and (b), each time omitting a different observation (y_1, y_2, …, y_{47}) from calibration;

d) Aggregate the predictions from the various steps (b) into a single "predicted" series

($\hat{y}_{(1)}$, $\hat{y}_{(2)}$, …, $\hat{y}_{(47)}$);

e) Compare the aggregated predictions ($\hat{y}_{(i)}$, $i = 1, 2, \ldots, 47$) with the original observations (y_i, $i = 1, 2, \ldots, 47$) and compute the *PRESS* statistic, which is defined as Eq. 4.19 (Montgomery *et al.*, 2006).

$$\mathrm{PRESS} = \sum_{i=1}^{n} [\mathrm{y_i} - \hat{\mathrm{y}}_{(\mathrm{i})}]^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(Eq. 4.19)}$$

where y_i is the ith observed value, $\hat{y}_{(i)}$ is the predicted value of the ith response based on all observations except the ith one.

f) Compare R^2 from the least square fit for all 47 observations and the R^2 – like statistic for prediction, which is defined as Eq. 4.20 (Montgomery *et al.*, 2006).

$$\mathrm{R}^2_{\mathrm{prediction}} = 1 - \frac{\mathrm{PRESS}}{\mathrm{SS_T}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(Eq. 4.20)}$$

where SS_T is the Total Sum of Squares. $R^2_{prediction}$ measures in an approximate sense how much of the variability in new observations the model might be expected to explain (Montgomery *et al.*, 2006).

From the above procedures and the definitions of LOOCV /PRESS, it would initially seem that calculating the PRESS statistic requires fitting *n* different regressions. Nevertheless, according to Montgomery *et al.* (2006), it is possible to calculate

PRESS statistic from the results of a single least-squares fit to all *n* observations. A simple formula for computing *PRESS* statistic is given in Eq. 4.21 (Montgomery *et al.,* 2006).

$$\mathrm{PRESS} = \sum_{i=1}^{n}\left(\frac{\mathrm{e_i}}{1-\mathrm{h_{ii}}}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 4.21)}$$

where e_i is the ordinary residual from a least-squares fit to all *n* observations, and $h_{ii} = x'_i (X' X)^{-1} x_i$.

4.5 Summary

This chapter presented the information regarding research design, data collection methods, data analysis methods and data sample characteristics. It explained that a quantitative research approach and a regression/correlation research design are suitable to be adopted in this study. Multiple data collection techniques, such as structured interviews, archival data and questionnaire were used to collect data for this study. The data collection instrument is a specially designed questionnaire. Correlation and regression analyses were adopted as the main data analysis methods. LOOCV (or PRESS) was used in this study to validate the regression models.

CHAPTER FIVE

DATA ANALYSIS

CHAPTER 5: DATA ANALYSIS

5.1 Introduction

This chapter reports the analysis of data collected. The raw data were presented using descriptive statistics and graphical techniques (e.g. Scattergram and Histogram). The data were then analyzed using correlation, regression and optimization techniques. Section 5.2 reports the main features of the sample and the data collected. Section 5.3 addresses objective 1 (i.e., to examine the effects of safety investments on safety performance of building projects) and objective 2 (i.e., to develop a model for determining safety performance of building projects) of this study. Hypothesis 1 (i.e., safety performance of building projects is determined by safety investments, safety culture and project hazard level as well as their interactions) and its sub-hypotheses are also tested in Section 5.3. Section 5.4 analyzes the costs of accidents to building contractors (objective 3 of this study) and tests hypotheses 2 and its sub-hypotheses. Section 5.5 addresses objective 4 (i.e., to study the optimization of safety investments for building projects). In this section, the curves of voluntary safety investments (VSIR curve), total accident costs (TACR curve), and total controllable safety costs (TCCR curve) are plotted under different project conditions. The financially optimum level of voluntary safety investments is quantified with three levels of safety culture and three levels of project hazard.

5.2 Characteristics of sample and data

5.2.1 Response

Out of 117 contractors contacted (see Section 4.3.3), 23 participated in this study representing a response rate of 20 per cent. The distribution of the 23 contractors is shown in Table 5.1. The response rate ranges from 14 per cent to 29 per cent among different BCA grades. Table 5.1 shows that the response rate of large contractors (grade A1 and A2) is higher than that of smaller contractors (grade B1 and B2). The grade B2 contractors have the lowest response rate (14%) among the four grades. The relatively lower response rate in grade B1 and B2 contractors may be attributed to the fact that a considerable part of their contracts are subcontracts, especially for B2 contractors (Teo and Feng, 2011). Thus, it is possible that there were no building projects having been completed by some small companies as the main contractor within the past three years (Teo and Feng, 2011).

Table 5.1: Distribution of Contractors

BCA Grade	*A1*	*A2*	*B1*	*B2*	*Total*
Population	35	27	57	115	234
Sampling frame	18	14	28	57	117
Sample contractors	5	4	6	8	23
Response rate*	28%	29%	21%	14%	20%

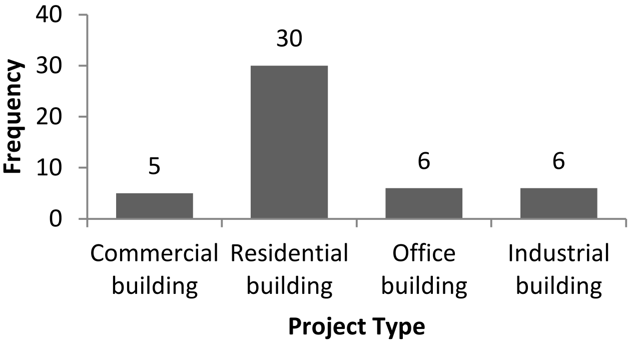
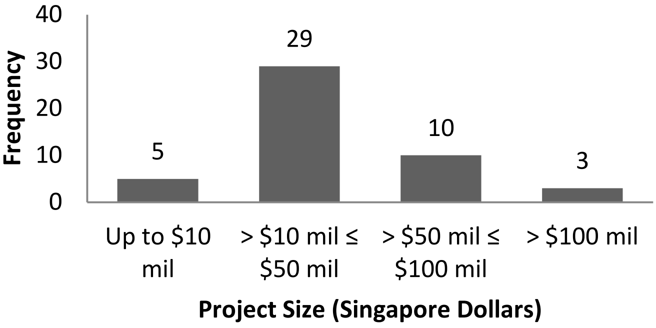
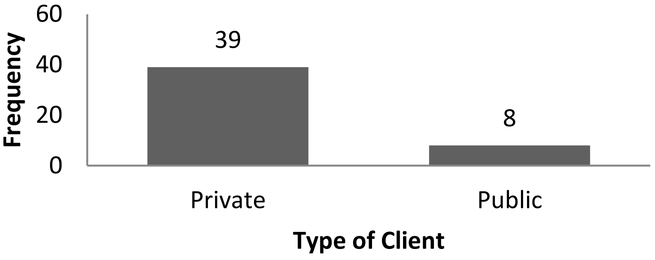
**Rounding-off error may have occurred.*

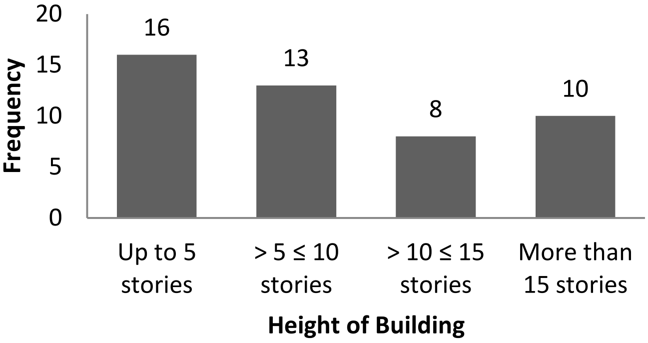
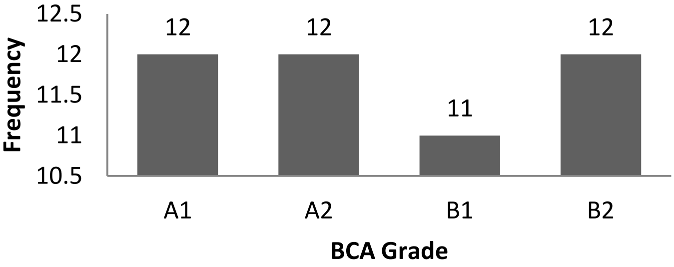
5.2.2 Profile of projects

The 23 contractors provided information of 47 completed building projects. The distributions of the sample projects are shown in Table 5.2. The types of the projects comprise commercial building (10.6%), residential building (63.8%), office building

(12.8%) and industrial building (12.8%). The contract sum of most projects (83%) ranges from SGD 10 million to SGD 100 million. Eighty-three per cent of the projects are from private sector, and 17 per cent are from public sector. The sample projects are evenly distributed among the four BCA grades. The profile of the projects suggests that the data were collected from a wide range of building projects with a focus on residential (63.8%), middle-size (83%) and private building projects (83%).

Table 5.2: Characteristics of Sample

Profile	Number	Percent*	Histogram
Project Type			
Commercial building	5	10.6%	
Residential building	30	63.8%	
Office building	6	12.8%	
Industrial building	6	12.8%	
Total	47	100%	
Project Size (Singapore Dollars)			
Up to $10 mil	5	10.6%	
> $10 mil ≤ $50 mil	29	61.7%	
> $50 mil ≤ $100 mil	10	21.3%	
> $100 mil	3	6.4%	
Total	47	100%	
Type of Client			
Private	39	83.0%	
Public	8	17.0%	
Total	47	100%	

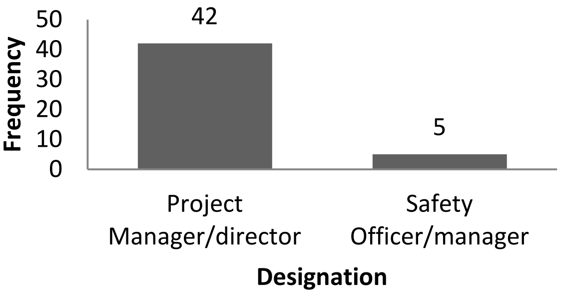
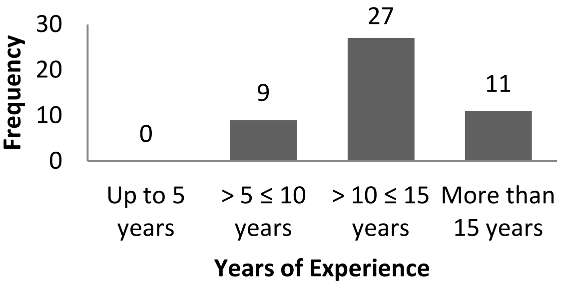
Profile	Number	Percent*	Histogram
Height of Building			
Up to 5 stories	16	34.0%	
> 5 ≤ 10 stories	13	27.7%	
> 10 ≤ 15 stories	8	17.0%	
More than 15 stories	10	21.3%	
Total	47	100%	
Firm's BCA grade			
A1	12	25.5%	
A2	12	25.5%	
B1	11	23.4%	
B2	12	25.5%	
Total	47	100%	

**Rounding-off error may have occurred.*

5.2.3 Profile of respondents

As shown in Table 5.3, the interviewees /key contact persons of involved projects consist of 42 project managers and 5 safety officers. Each of the interviewees /key contact persons provided the information of one completed building project. The 47 interviewees /key contact persons came from the 23 sample contractors. Out of the 23 contractors, 5 provided 1 interviewee; 12 provided 2 interviewees; and 6 provided 3 interviewees. Most of the interviewees or key contact persons were project managers/directors, and had more than 10 years of experience in construction industry. The average working experience of the interviewees or key contact persons was 13 years, and the minimum working experience was 7 years.

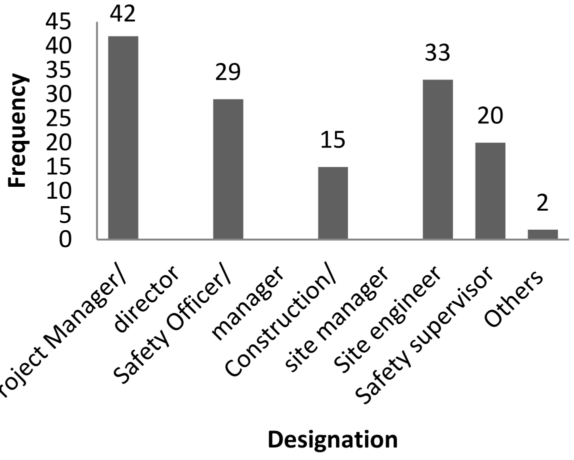
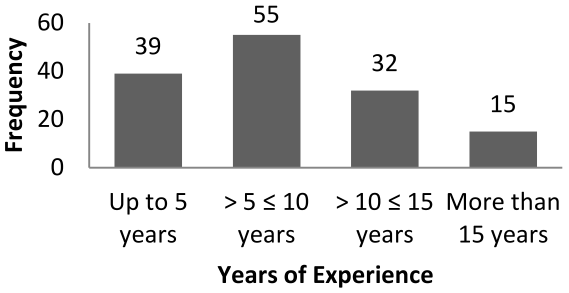
Table 5.3: Profile of Interviewees /Key Contact persons

Profile	Number	Percent*	Histogram
Designation			
Project Manager/ director	42	89.4%	
Safety Officer/ manager	5	10.6%	
Total	47	100%	
Years of experience in construction industry			
Up to 5 years	0	0	
> 5 ≤ 10 years	9	19.1%	
> 10 ≤ 15 years	27	57.5%	
More than 15 years	11	23.4%	
Total	47	100%	

**Rounding-off error may have occurred.*

As stated in Section 4.3.6, for each of the interviewed projects, in order to enhance the data validity, three members of site management staff, such as project managers/directors, construction/site managers, site engineers, safety managers/officers, and safety supervisors were requested to complete the Section E (project hazard level) and F (safety culture of the project) of the data collection instrument. The questionnaires were directly handed over to the three respondents, who were requested to fill out Sections E and F before eyes. A total of 141 site management staff members responded to the questionnaire. The profile of these questionnaire respondents was described in Table 5.4, which shows that over 70 per cent of the respondents have more than 5 years of experience in construction industry.

Table 5.4: Profile of Questionnaire Respondents

Profile	*Number*	*Percent**	*Histogram*
Designation			
Project Manager/ director	42	29.8%	
Safety Officer/ manager	29	20.6%	
Construction/ site manager	15	10.6%	
Site engineer	33	23.4%	
Safety supervisor	20	14.2%	
Others	2	1.4%	
Total	141	100%	
Years of experience in construction industry			
Up to 5 years	39	27.7%	
> 5 ≤ 10 years	55	39.0%	
> 10 ≤ 15 years	32	22.7%	
More than 15 years	15	10.6%	
Total	141	100%	

**Rounding-off error may have occurred.*

5.2.4 Characteristics of data

Before inferential statistical analyses were carried out, the characteristics of data collected was illustrated through descriptive statistics and graphical techniques, such as the frequency histogram, box plots, scattergrams, etc.

<u>5.2.4.1 Contract value</u>

The descriptive statistics for contract value are presented in Table 5.5. The contract values of the 47 sample projects range from SGD 7 million to SGD 245 million with a mean value of SGD 41.38 million and a standard deviation of 43.24. To examine the shape of the distributions of the contract values, the frequencies of values are plotted in Figure 5.1, which indicates a marked positively skewed (Skewness > 2 * Std. Error) distribution of these data.

Table 5.5: Descriptive Statistics (Contract Value S$ mil)

	Statistics	Std. Error
N (Valid / Missing)	47 / 0	
Mean	41.38	6.31
Median	26.00	
Std. Deviation	43.24	
Variance	1869.34	
Skewness	2.86	0.35
Kurtosis	10.48	0.68
Range	238.00	
Minimum	7.00	
Maximum	245.00	

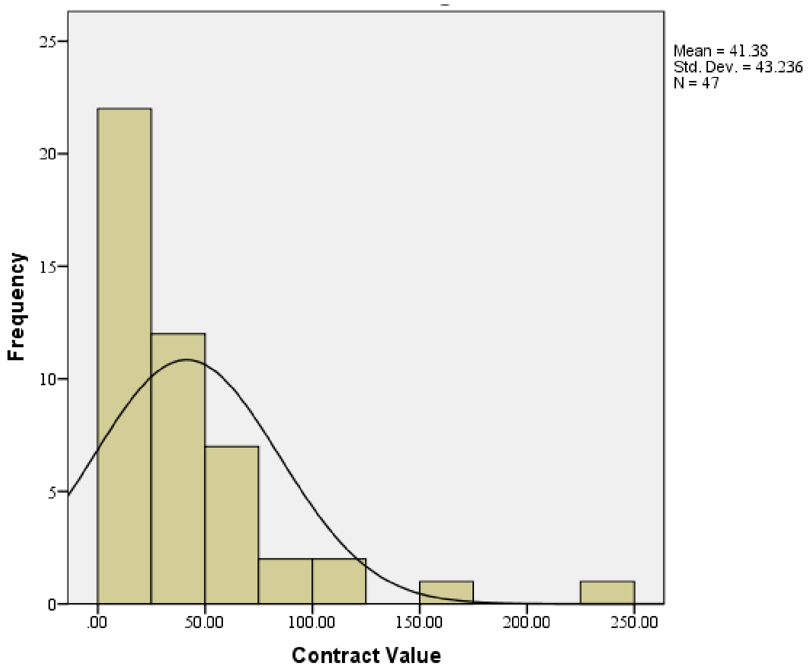


Figure 5.1: Histogram (Contract Value)

5. 2.4.2 Firm's BCA grade

The descriptive statistics for firm's BCA grade are presented in Table 5.6 and the frequencies of values are plotted in Figure 5.2. Figure 5.2 shows that the sample projects are almost evenly distributed among different BCA grades and the shape indicates a normally distributed data (Skewness < 2 * Std. Error).

Table 5.6: Descriptive Statistics (Firm's BCA Grade)

	Statistics	Std. Error
N (Valid / Missing)	47 / 0	
Mean	2.49	0.166
Median	2.00	
Std. Deviation	1.14	
Variance	1.299	
Skewness	0.027	0.35
Kurtosis	-1.40	0.68
Range	3	
Minimum	1	
Maximum	4	

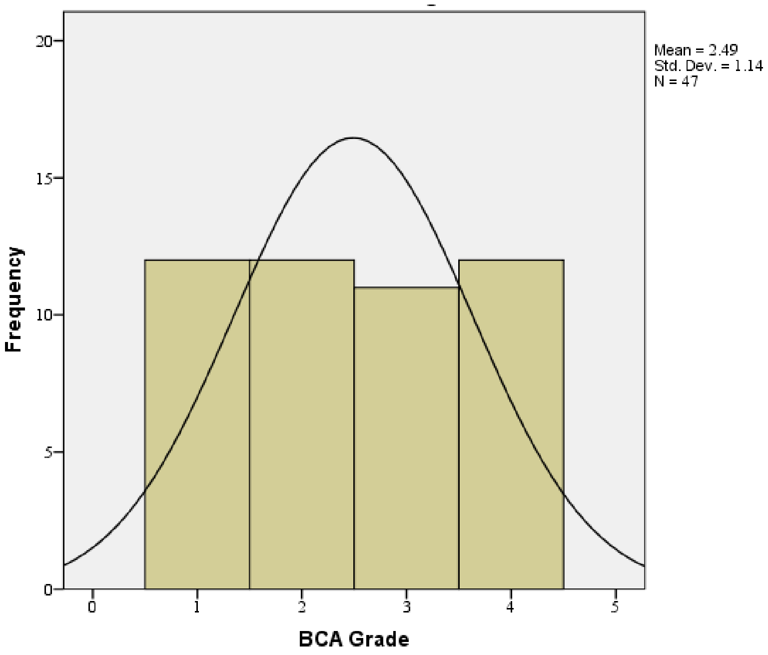


Figure 5.2: Histogram (Firm's BCA Grade)

5. 2.4.3 Duration of project

Table 5.7 reports the descriptive statistics for the data about the duration of projects. The duration of the 47 sample projects ranges from 14 months to 39 months with a mean value of 25.51 months and a standard deviation of 7.49. Figure 5.3 shows that these data can be viewed as approximately normal distribution (Skewness < 2 * Std. Error).

Table 5.7: Descriptive Statistics (Duration of Project)

	Statistics	Std. Error
N (Valid Missing)	47 / 0	
Mean	25.51	1.09
Median	24	
Std. Deviation	7.49	
Variance	56.04	
Skewness	0.21	0.35
Kurtosis	-1.32	0.68
Range	25	
Minimum	14	
Maximum	39	

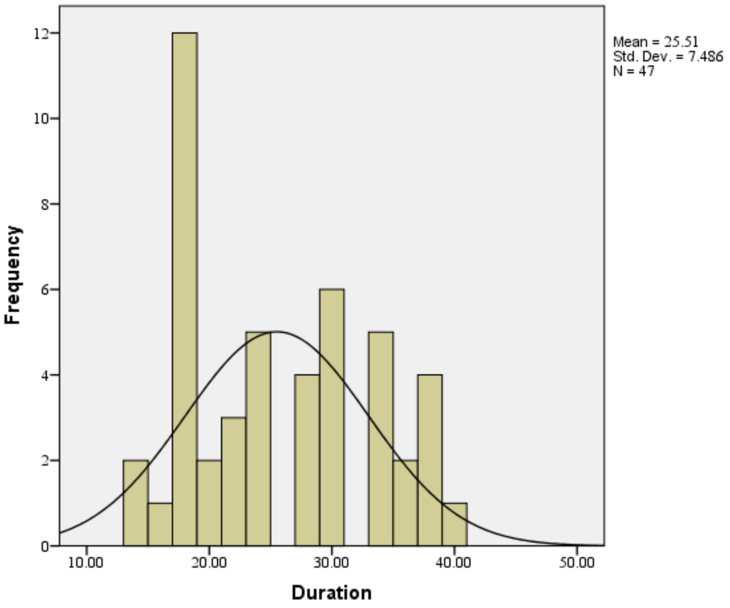


Figure 5.3: Histogram (Duration of Project)

5. 2.4.4 Height of building

Table 5.8 reports the descriptive statistics for the data about the height of building. The height of building of the 47 sample projects ranges from 2 storeys to 28 storeys with a mean value of 10.1 storeys and a standard deviation of 6.72. The histogram (see Figure 5.4) indicates a positive skew for these data (Skewness > 2 * Std. Error).

Table 5.8: Descriptive Statistics (Height of Building)

	Statistics	Std. Error
N (Valid / Missing)	47 / 0	
Mean	10.1	0.98
Median	9.00	
Std. Deviation	6.72	
Variance	45.14	
Skewness	0.91	0.35
Kurtosis	-0.003	0.68
Range	26	
Minimum	2	
Maximum	28	

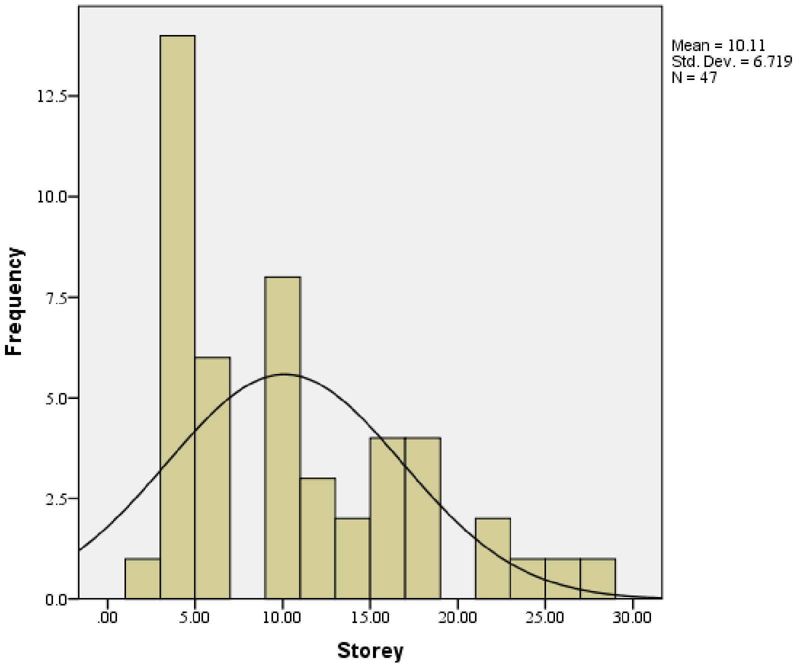


Figure 5.4: Histogram (Height of Building)

5. 2.4.5 Percentage of work completed by subcontractors

Table 5.9 reports the descriptive statistics for the data about the percentage of work completed by subcontractors. This percentage ranges from 30 per cent to 95 per cent with a mean percentage of 61.28 per cent and a standard deviation of 16.99. The histogram (see Figure 5.5) indicates an approximately normal distribution for these data (Skewness < 2 * Std. Error).

Table 5.9: Descriptive Statistics (Percentage of Work Completed by Subcontractors)

	Statistics	Std. Error
N (Valid / Missing)	47 / 0	
Mean	61.28	2.48
Median	60.00	
Std. Deviation	16.99	
Variance	288.55	
Skewness	0.12	0.35
Kurtosis	-1.00	0.68
Range	65.00	
Minimum	30.00	
Maximum	95.00	

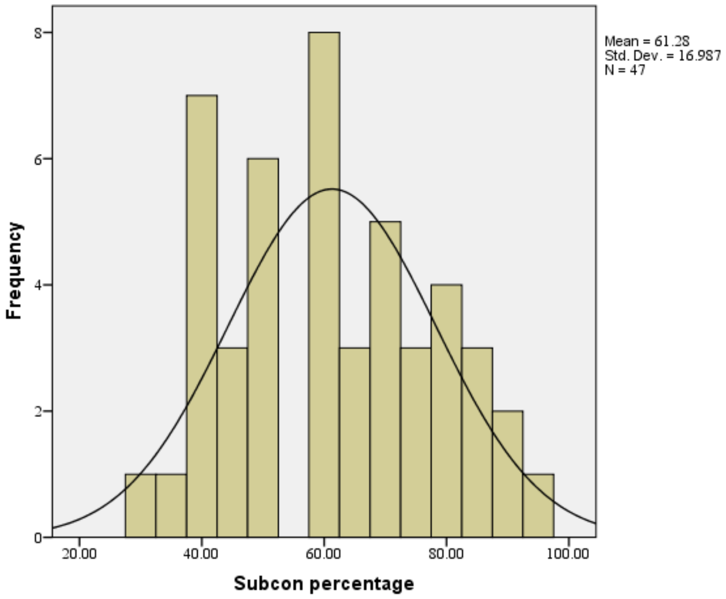


Figure 5.5: Histogram (Percentage of Work Completed by Subcontractors)

5. 2.4.6 Accident severity rate (ASR)

Table 5.10 reports the descriptive statistics for the data about ASR. The ASR of sample projects ranges from 6.1 to 2888.2 with a mean value of 342.94 and a standard deviation of 489.56. The histogram (see Figure 5.6) indicates a large positive skew for these data (Skewness > 2 * Std. Error).

Table 5.10: Descriptive Statistics (ASR)

	Statistics	Std. Error
N (Valid / Missing)	47 / 0	
Mean	342.94	71.41
Median	217.30	
Std. Deviation	489.56	
Variance	239666.26	
Skewness	3.70	0.35
Kurtosis	16.58	0.68
Range	2882.1	
Minimum	6.10	
Maximum	2888.20	

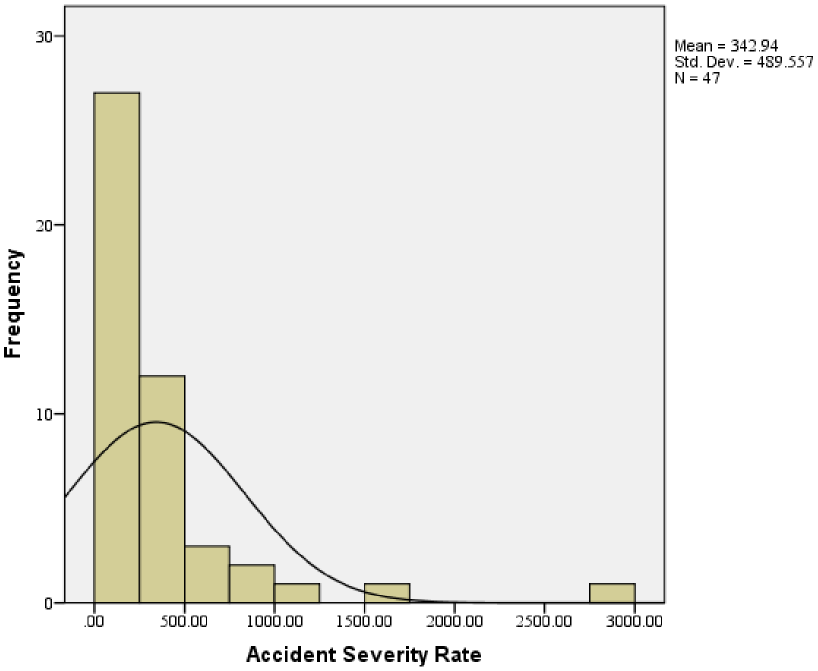


Figure 5.6: Histogram (ASR)

5. 2.4.7 Accident frequency rate (AFR)

Table 5.11 reports the descriptive statistics for the data about AFR. The AFR of sample projects ranges from 1.53 to 58.33 with a mean value of 21.10 and a standard deviation of 12.53. The histogram (see Figure 5.7) indicates a positive skew for these data (Skewness > 2 * Std. Error).

Table 5.11: Descriptive Statistics (AFR)

	Statistics	Std. Error
N (Valid / Missing)	47 / 0	
Mean	21.10	1.83
Median	19.28	
Std. Deviation	12.53	
Variance	156.90	
Skewness	0.99	0.35
Kurtosis	0.96	0.68
Range	56.80	
Minimum	1.53	
Maximum	58.33	

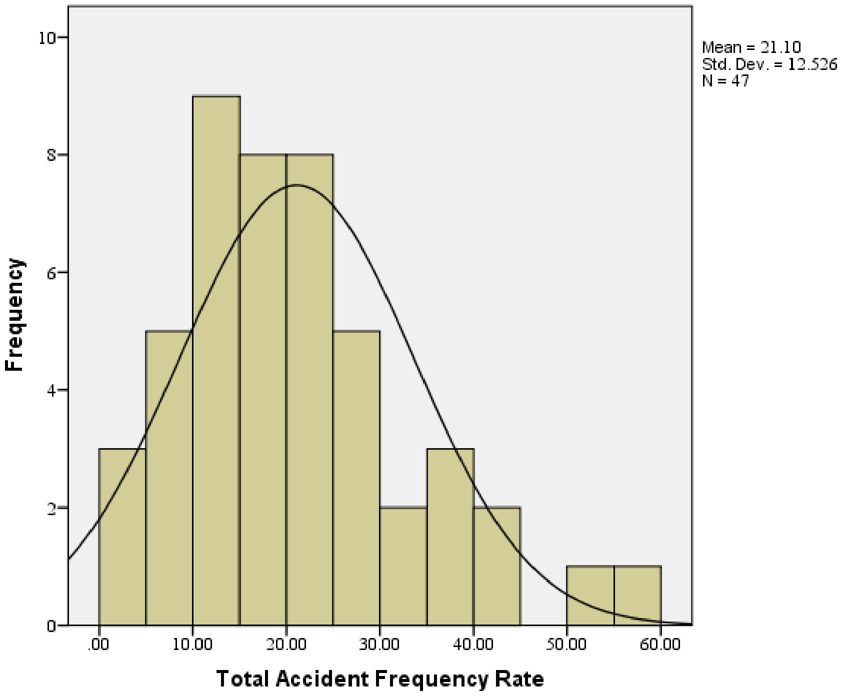


Figure 5.7: Histogram (AFR)

5. 2.4.8 Total safety investments ratio (TSIR)

Table 5.12 reports the descriptive statistics for the data about total safety investments ratio. The total safety investments of sample projects account for 1.62%-3.00% of total contract sum with a mean percentage of 2.05% and a standard deviation of 0.27%. Figure 5.8 indicates a positive skew for these data (Skewness >2 * Std. Error).

Table 5.12: Descriptive Statistics (TSIR)

		Statistics	Std. Error
N	Valid	47	
	Missing	0	
Mean		2.05	0.04
Median		2.03	
Std. Deviation		0.27	
Variance		0.074	
Skewness		0.97	0.35
Kurtosis		2.04	0.68
Range		1.38	
Minimum		1.62	
Maximum		3.00	

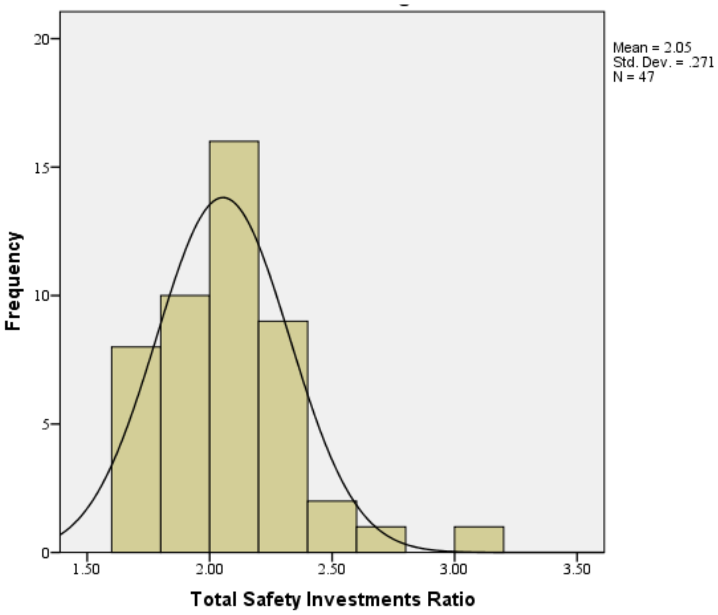


Figure 5.8: Histogram (TSIR)

5. 2.4.9 Basic safety investments ratio (BSIR)

Table 5.13 reports the descriptive statistics for the data about basic safety investments ratio. The basic safety investments of sample projects account for 1.20%-2.22% of total contract sum with a mean percentage of 1.59% and a standard deviation of 0.20%. The histogram (see Figure 5.9) indicates an approximate normal distribution for these data (Skewness < 2 * Std. Error).

Table 5.13: Descriptive Statistics (BSIR)

	Statistics	Std. Error
N (Valid / Missing)	47 / 0	
Mean	1.59	0.03
Median	1.58	
Std. Deviation	0.20	
Variance	0.04	
Skewness	0.66	0.35
Kurtosis	1.142	0.68
Range	1.02	
Minimum	1.20	
Maximum	2.22	

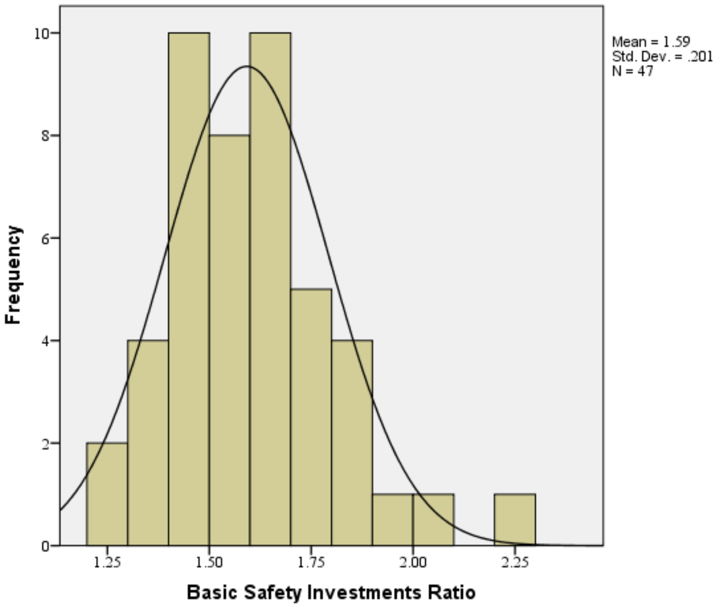


Figure 5.9: Histogram (BSIR)

5. 2.4.10 Voluntary safety investments ratio (VSIR)

Table 5.14 reports the descriptive statistics for the data about voluntary safety investments ratio. The voluntary safety investments of sample projects account for 0.30%-0.78% of total contract sum with a mean percentage of 0.46% and a standard deviation of 0.11%. The histogram (see Figure 5.10) indicates a marked positive skew for these data (Skewness > 2 * Std. Error).

Table 5.14: Descriptive Statistics (VSIR)

	Statistics	Std. Error
N (Valid /Missing)	47 /0	
Mean	0.46	0.17
Median	0.44	
Std. Deviation	0.11	
Variance	0.01	
Skewness	1.05	0.35
Kurtosis	0.79	0.68
Range	0.48	
Minimum	0.30	
Maximum	0.78	

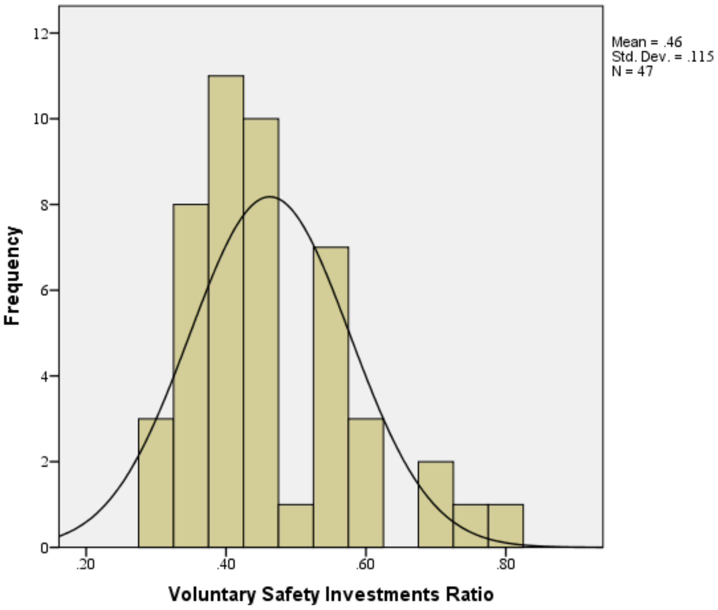


Figure 5.10: Histogram (VSIR)

5.2.4.11 Project hazard index (PHI)

Table 5.15 reports the descriptive statistics for the data about project hazard index. The PHI of sample projects ranges from 1.63 to 4.03 with a mean value of 2.90 and a standard deviation of 0.54. The histogram (see Figure 5.11) indicates an approximately normal distribution for these data (Skewness < 2 * Std. Error).

Table 5.15: Descriptive Statistics (PHI)

		Statistics	Std. Error
N	Valid	47	
	Missing	0	
Mean		2.90	0.08
Median		2.81	
Std. Deviation		0.54	
Variance		0.29	
Skewness		0.14	0.35
Kurtosis		-0.42	0.68
Range		2.40	
Minimum		1.63	
Maximum		4.03	

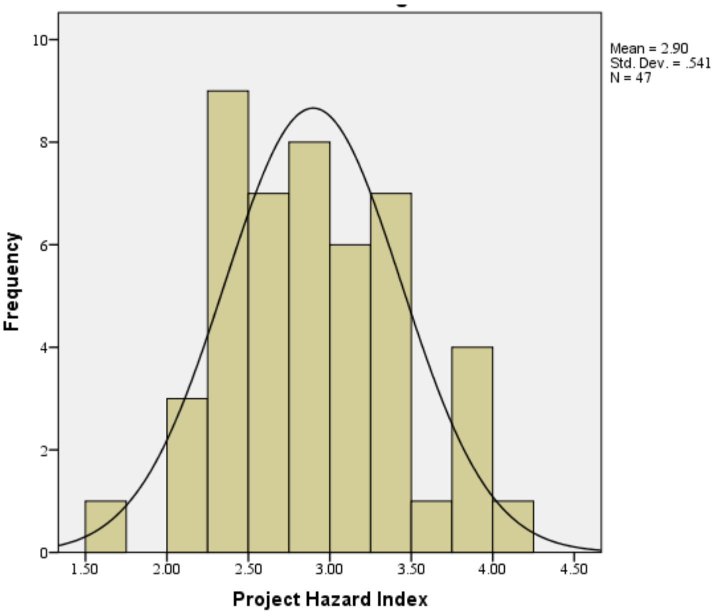


Figure 5.11: Histogram (PHI)

5.2.4.12 Safety culture index (SCI)

Table 5.16 reports the descriptive statistics for the data about safety culture index. The SCI of sample projects ranges from 3.25 to 4.02 with a mean value of 3.58 and a standard deviation of 0.18. The histogram (see Figure 5.12) indicates an approximately normal distribution for these data (Skewness < 2 * Std. Error).

Table 5.16: Descriptive Statistics (SCI)

	Statistics	Std. Error
N (Valid /Missing)	47 /0	
Mean	3.58	0.03
Median	3.59	
Std. Deviation	0.18	
Variance	0.03	
Skewness	0.20	0.35
Kurtosis	-0.24	0.68
Range	0.77	
Minimum	3.25	
Maximum	4.02	

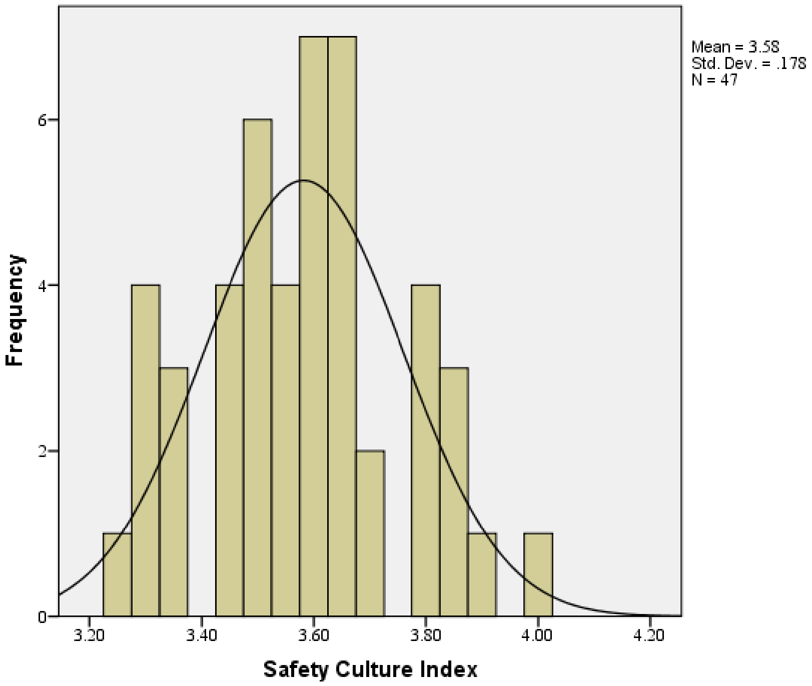


Figure 5.12: Histogram (SCI)

5.2.4.13 Total accident costs ratio (TACR)

Table 5.17 reports the descriptive statistics for the data about total accident costs ratio. The total accident costs of sample projects ranges from 0.12% of contract sum to 0.83% of contract sum with a mean value of 0.25% of contract sum and a standard deviation of 0.14%. The histogram (see Figure 5.13) indicates quite a large positive skew for these data (Skewness > 2 * Std. Error).

Table 5.17: Descriptive Statistics (TACR)

	Statistics	Std. Error
N (Valid /Missing)	47 /0	
Mean	0.25	0.02
Median	0.2	
Std. Deviation	0.14	
Variance	0.02	
Skewness	2.37	0.35
Kurtosis	6.07	0.68
Range	0.71	
Minimum	0.12	
Maximum	0.83	

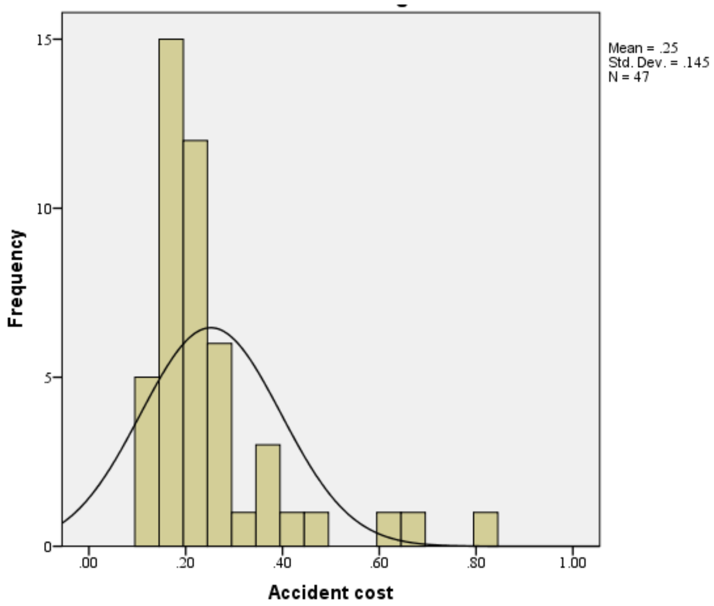


Figure 5.13: Histogram (TACR)

The descriptive statistics and the histograms indicate that some variables (e.g. Duration of project, firm's BCA grade, percentage of work completed by subcontractors, BSIR, SCI and PHI) have approximately normal distribution; while some may not have normal distribution (e.g. Contract value, height of building, ASR, AFR, TSIR, VSIR and TACR). Data transformation may be necessary when the variables that are not normally distributed are used to perform some types of statistical analyses which make the assumption of normally distributed data. Moreover, the interpretation of the statistical results deserves meticulous cautions (Dancey and Reidy, 2004).

5.3 Factors influencing safety performance of building projects

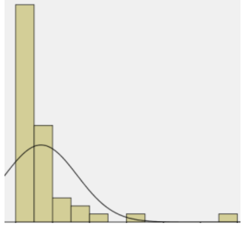
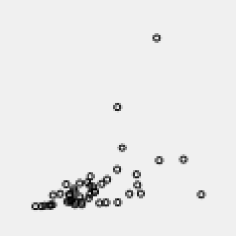
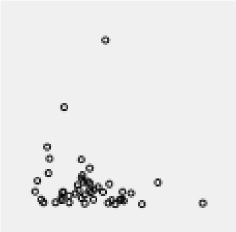
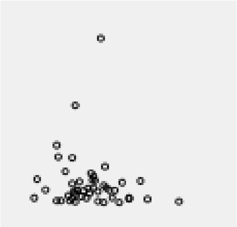
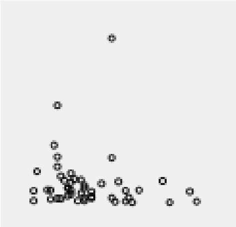
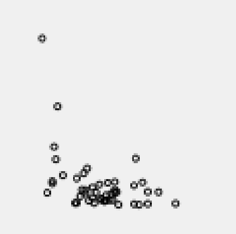
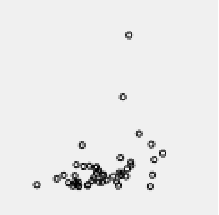
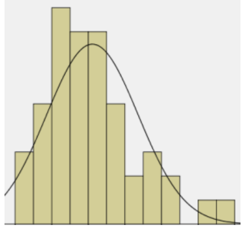
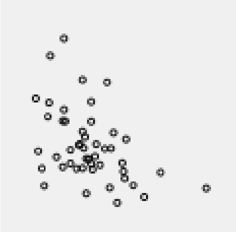
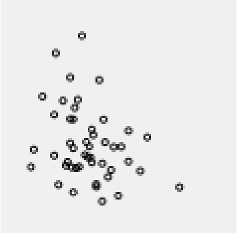
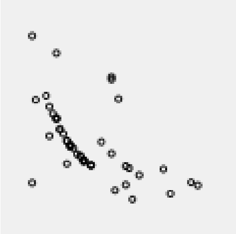
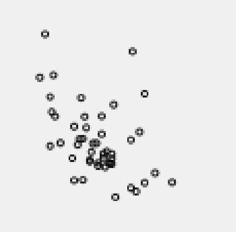
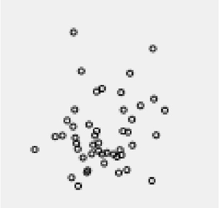
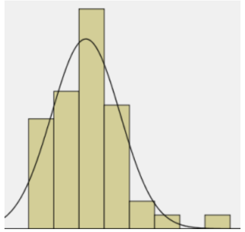
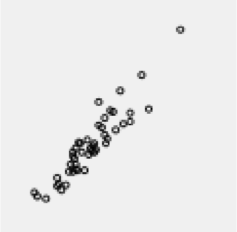
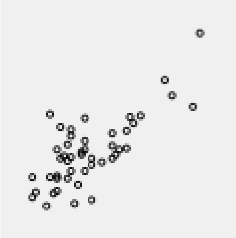
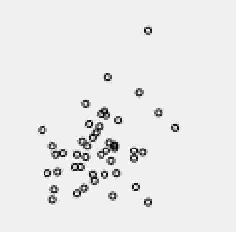
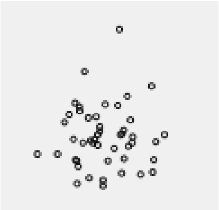
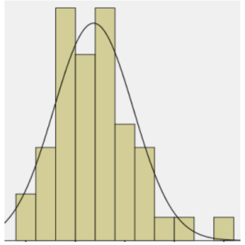
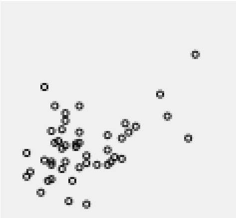
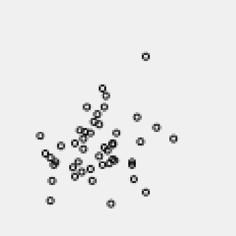
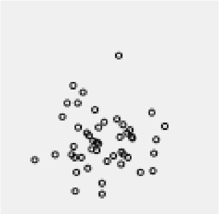
5.3.1 Bivariate correlations

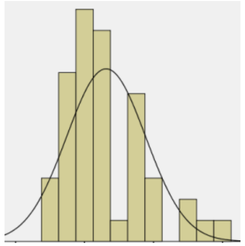
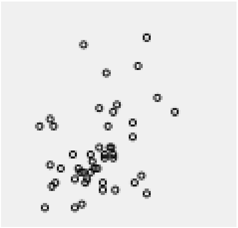
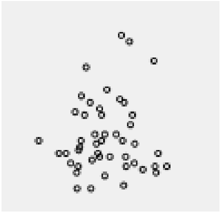
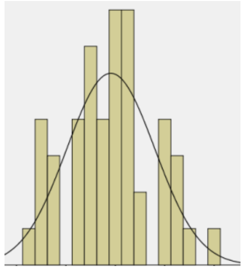
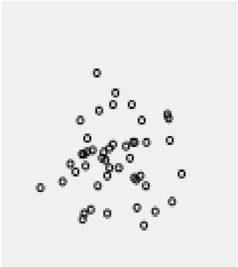
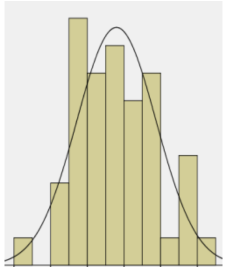
Bivariate correlation analysis (see Section 4.4.1) was conducted to identify the factors influencing safety performance (measured by AFR and ASR) of building projects. Although the descriptive statistics indicate that some variables (e.g. ASR, AFR, TSIR and VSIR) do not have normal distributions, Moore (2000) suggests that, with a sample size greater 40, the statistical inference is quite robust in Pearson correlations. Thus, no data transformation was conducted. Figure 5.14 presents the bivariate correlation coefficients, distributions of variables, and scatter plot which may indicate some relationships between variables. Figure 5.14 shows that Accident Severity Rate (ASR) is significantly ($p<0.05$) correlated with Safety Culture Index (SCI) ($r=-0.46$)

and Project Hazard Index (PHI) (r=0.363). Accident Frequency Rate (AFR) is significantly (p<0.05) correlated with Total Safety Investments Ratio (TSIR) (r=-0.436), Basic Safety Investments Ratio (BSIR) (r=-0.282), Voluntary Safety Investments Ratio (VSIR) (r=-0.539), and SCI (r=-0.439). This result shows that the two safety performance indicators (AFR and ASR) are correlated with different sets of variables. The specific effects of variables on the two safety performance indicators are analyzed in Sections 5.3.2, 5.3.3, 5.3.4 and 5.3.5. The relationship between AFR and ASR is analyzed in Section 5.3.6. A further discussion about the two safety performance indicators is provided in Section 6.2.

The results (see Figure 5.14) also show that the correlation between Voluntary Safety Investments Ratio (VSIR) and AFR (r = -0.539, p = 0.000) is much stronger than the correlation between Basic Safety Investments Ratio (BSIR) and AFR (r = -0.282, p = 0.045). It is possible that different types of safety investments play different roles in determining safety performance of building projects. The effects of basic safety investments and voluntary safety investments on safety performance are analyzed in Section 5.3.3 and Section 5.3.4, respectively. Further discussions about the basic safety investments and voluntary safety investments are provided in Section 6.3 and Section 6.4, respectively.

Figure 5.14: Correlations and Scatterplot Matrix

	ASR	AFR	TSIR	BSIR	VSIR	SCI	PHI
ASR							
AFR	0.512(**)						
TSIR	-0.119	-0.436(**)					
BSIR	-0.099	-0.282(*)	0.925(**)				

	ASR	AFR	TSIR	BSIR	VSIR	SCI	PHI
VSIR	-0.109	-0.539(**)	0.749(**)	0.442(**)			
SCI	-0.460(**)	-0.439(**)	0.316(*)	0.230	0.347(*)		
PHI	0.363(*)	0.155	0.023	-0.007	0.067	0.061	

* *p*< 0.05 (2-tailed); ** *p*<0.01 (2-tailed).

Moreover, SCI was found to be positively correlated with VSIR ($r = 0.347$, $p < 0.05$) and TSIR ($r = 0.316$, $p < 0.05$), while no significant ($p > 0.05$) relationship was found between BSIR and SCI ($r = 0.23$). As shown in Figure 5.14, AFR is significantly ($p<0.05$) correlated with TSIR (r=-0.436), VSIR (r=-0.539) and SCI (r=-0.439). It is possible that the increase in total safety investments or voluntary safety investments leads to the improvement of safety culture, which then transmits the effects of total safety investments or voluntary safety investments to the safety performance. The effects of TSIR and VSIR on AFR are likely to be mediated by SCI. The mediated effects of TSIR and VSIR on AFR are tested in Section 5.3.2 and Section 5.3.4, respectively.

5.3.2 Effects of total safety investments on safety performance

This section examines the effects of total safety investments on safety performance of building projects. In this study, it was hypothesized that the effect of safety investments on safety performance varies with the level of safety culture and project hazard level (see hypothesis 1.4 and hypothesis 1.5 in Section 3.2). Moderated regression analysis (see Section 4.4.3) was used to test whether safety culture level and project hazard level modify the relationship between total safety investments and AFR; and the results are reported in Section 5.3.2.1.

As discussed in the previous section (Section 5.3.1), the effects of total safety investments on safety performance are likely to be mediated by safety culture level. The mediation effects were tested using the regression methods suggested by Baron and Kenny (1986) (see Section 4.4.4); and the results are presented in Section 5.3.2.2.

Based on the results of bivariate correlation analysis (see Section 5.3.1), TSIR was significantly correlated with AFR, while no significant relationship was found between TSIR and ASR. Thus, AFR was used as the safety performance indicator when testing the moderation effects and mediation effects of total safety investments to safety performance.

Before the regression analyses are performed, the basic assumptions (refer to Section 4.4.2 for details) underlying regression analysis were checked. As shown in Figure 5.14, the scatterplot matrix contains the scatterplot for all the metric variables in the data set. Examination of the scatterplots (Figure 5.14) does not reveal either apparent nonlinear relationships or a dramatically different type of dot cluster. The histograms of the variables (refer to Figures 5.7, 5.8, 5.11 and 5.12) indicate that the variables PHI and SCI have an approximate normal distribution, whilst variables AFR and TSIR exhibit positively skewed distribution. As regression analysis has been shown to be quite robust even when the normality assumptions are violated, then the original variables may be preferred for the comparability in the interpretation phase (Hair *et al.*, 1998). Thus, transformations are not deemed necessary.

The scatter plots were used to explore the potential patterns of the relationships between TSIR and AFR. To explore whether the patterns are different under different project hazard and safety culture conditions, five scattergrams are presented: (1) plotting the scatters using all cases (Figure 5.15); (2) plotting the scatters under higher project hazard level (i.e. when PHI >mean = 2.90) (see Figure 5.16); (3) plotting the scatters under lower project hazard level (i.e. when PHI ≤ 2.90) (see Figure 5.17); (4) plotting the scatters under higher safety culture level (i.e. when SCI > mean= 3.58) (see Figure 5.18); and (5) plotting the scatters under lower safety culture level (i.e. when SCI ≤ 3.58) (see Figure 5.19).

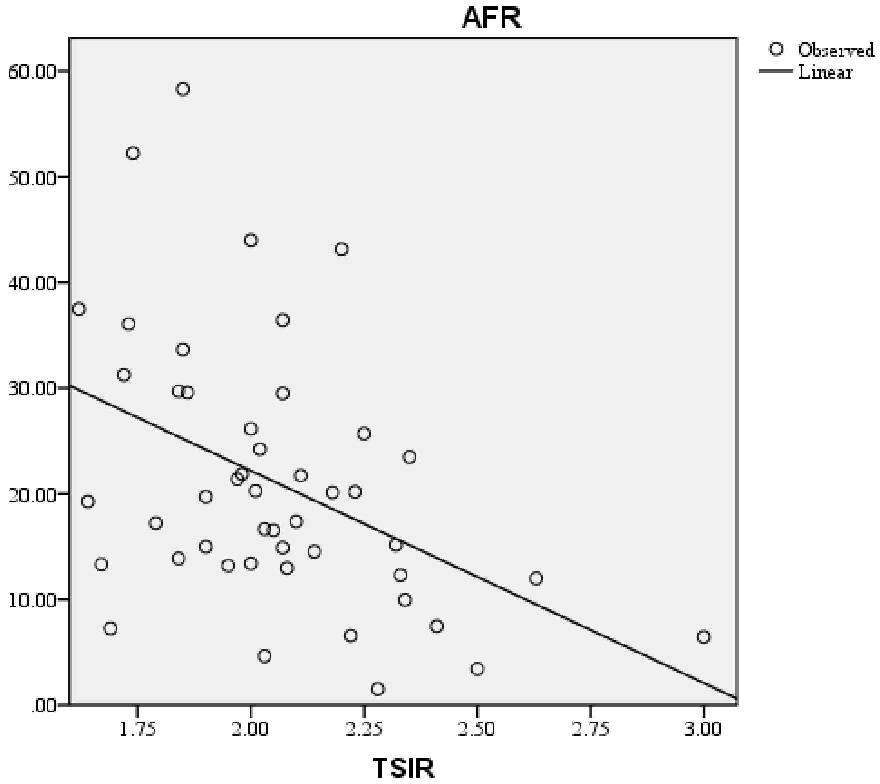


Figure 5.15: Plotting AFR on TSIR (All Cases)

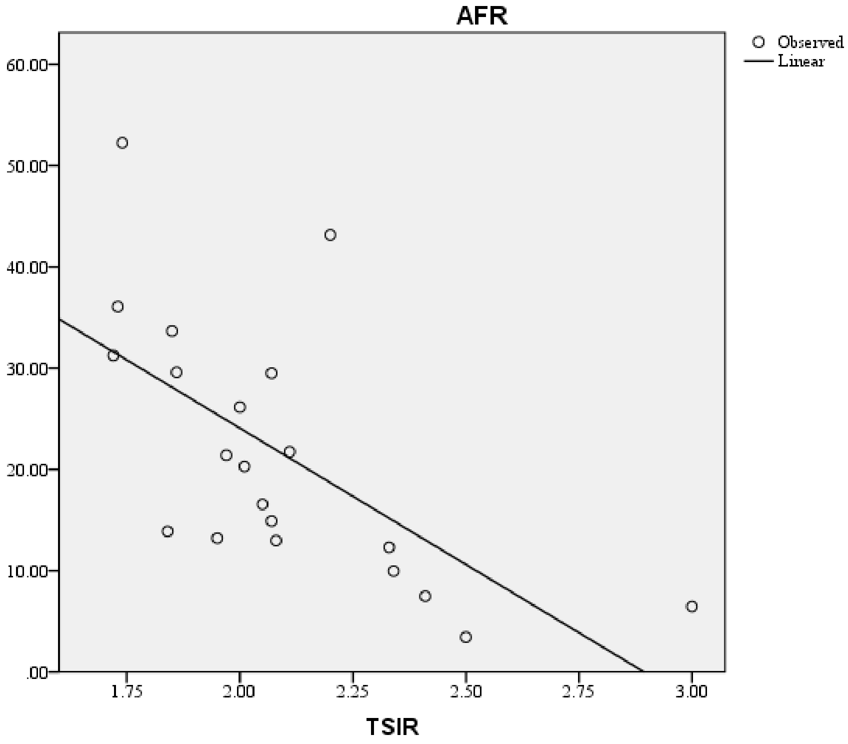


Figure 5.16: Plotting AFR on TSIR (when PHI >2.90)

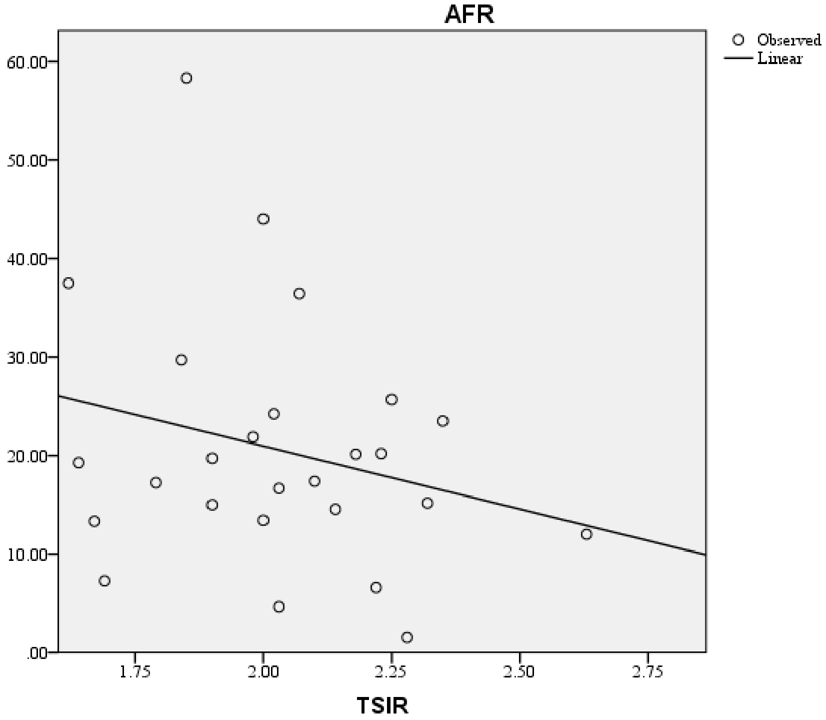


Figure 5.17: Plotting AFR on TSIR (when PHI ≤ 2.90)

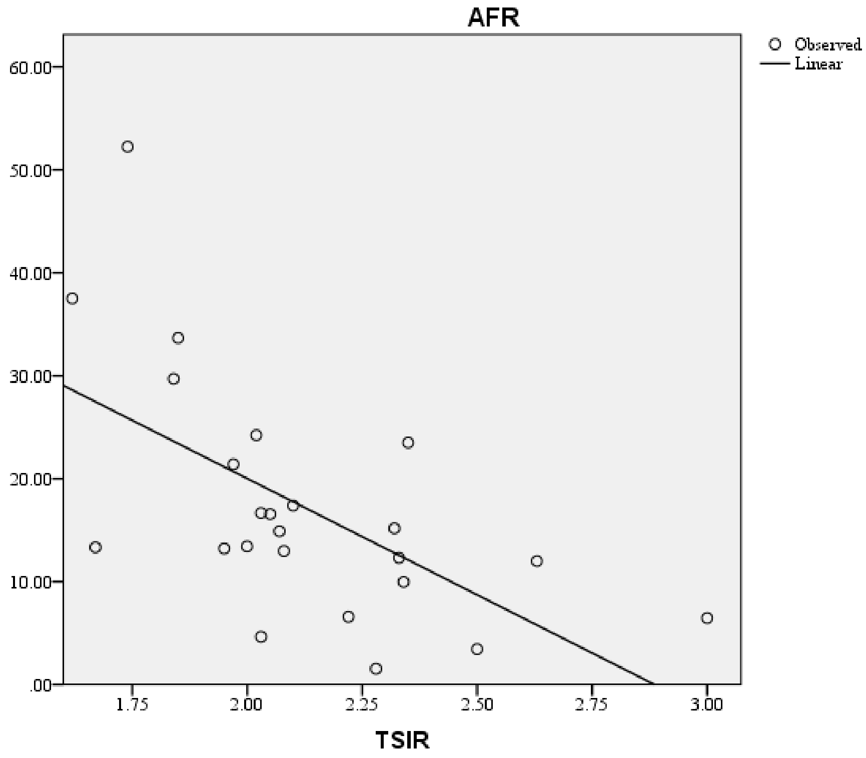


Figure 5.18: Plotting AFR on TSIR (when SCI > 3.58)

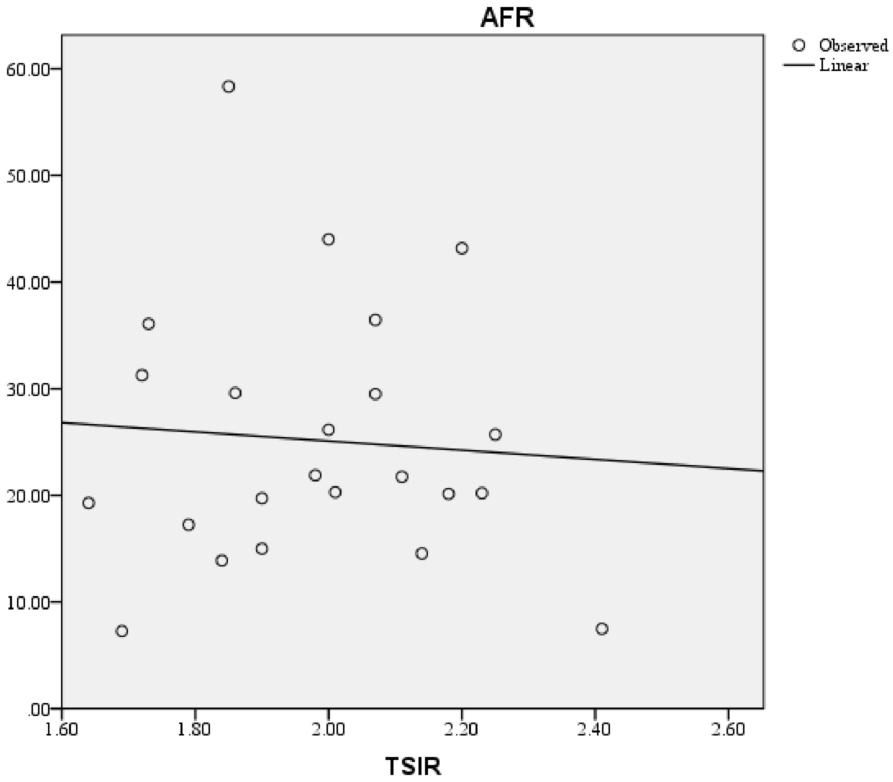


Figure 5.19: Plotting AFR on TSIR (when SCI ≤ 3.58)

From the Figures 5.15, 5.16, 5.17, 5.18 and 5.19, a general negative tendency of the relationship between AFR and TSIR is indicated. Furthermore, it seems that the relationship between TSIR and AFR does not show significant differences under different project hazard levels; while this relationship looks different under different safety culture levels. Section 5.3.2.1 uses the moderation and mediation analyses to further explore the potential relationship between AFR and TSIR.

5.3.2.1 Test of the moderated effects of total safety investments on safety performance

According to Aguinis (1995), to test whether a third variable affects the relationship between the dependent variable and the independent variable(s), moderated regression analysis can be used. The process of conducting the moderated regression analysis and the moderated regression model were presented in Section 4.4.3. The regression model for testing whether PHI affects the relationship between TSIR and AFR posits that AFR is a linear function of TSIR, PHI, and the interaction of TSIR and PHI (TSIR * PHI) (Eq. 5.1).

$$AFR = \beta_0 + \beta_1 \bullet TSIR + \beta_2 \bullet PHI + \beta_3 \bullet TSIR \bullet PHI + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.1)}$$

Where the intercept β_0 and the slopes (β_1, β_2, *and* β_3) are unknown constants, ε is a random error component.

The results of regression analysis are presented in Table 5.18 and Table 5.19. Table 5.19 shows that the effect of TSIR on AFR is significant ($p<0.01$). The regression coefficients for TSIR and PHI reflect conditional relationships: the regression coefficient for TSIR reflects the influence of TSIR on AFR when PHI is at the mean level (centred PHI = 0), and the coefficient for PHI reflects the effect of PHI on AFR when TSIR equals its mean value (centred TSIR = 0).

*Table 5.18: Model Summary (Regress AFR on TSIR, PHI and TSIR * PHI)*

Model Summary	
R	0.511
R^2	0.262
Adjusted R^2	0.210
Standard Error of the Estimate	11.13
F	5.077
Sig.	0.004
R^2 Contribution of the Product Term	0.044
Durbin-Watson	2.059

*Table 5.19: Model Coefficients (Regress AFR on TSIR, PHI and TSIR*PHI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	21.17	1.62	13.03	0.000
Centered *TSIR*	-18.82	6.11	-3.08	0.004
Centered *PHI*	3.16	3.06	1.03	0.306
Product term	-21.17	13.16	-1.60	0.115

From Table 5.19, the effect of the TSIR * PHI product variable on AFR is not significant ($p>0.05$) and, as can be seen in Table 5.18, the product variable only explains 4.4% of the variance in AFR. Thus, the relationship between the level of TSIR and AFR is not significantly moderated by project hazard level.

A moderated regression model was also developed to test whether the effect of TSIR on AFR is moderated by SCI. The results of moderation analysis are presented Tables 5.20 and 5.21. Table 5.21 shows that the interaction between TSIR and SCI

(TSIR*SCI) does not significantly affect AFR, which means that the effect of total safety investments on accident frequency rate is not moderated by the safety culture level of the project.

Table 5.20: Model Summary (Regress AFR on TSIR, SCI and TSIR SCI)*

Model Summary	
R	0.567
R^2	0.321
Adjusted R^2	0.274
Standard Error of the Estimate	10.67
F	6.8
Sig.	0.001
R^2 Contribution of the Product Term	0.031

*Table 5.21: Model Coefficients (Regress AFR on TSIR, SCI and TSIR *SCI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	21.76	1.62	13.37	0.000
Centered TSIR	-11.03	6.79	-1.62	0.111
Centered SCI	-24.84	9.35	-2.65	0.011
Product term	-44.65	31.71	-1.41	0.166

Nevertheless, it is noteworthy that, in this model, the effect of TSIR on AFR is no longer significant ($p>0.05$) with the effects of SCI and their interaction term on AFR being partialled out. This finding may further support the assumption (see Section 5.3.1) that the effects of total safety investments on safety performance are mediated by safety culture level.

In the next section, the mediated regression analysis was carried out to test whether there is a mediated effect of TSIR on AFR.

5.3.2.2 Test of the mediated effects of total safety investments on safety performance

Following the standard or hierarchical regression method suggested by Baron and Kenny (1986) (see Section 4.4.4), to test whether the effect of TSIR (independent variable) to AFR (dependent variable) is mediated/transmitted by SCI (mediator), three steps were carried out.

- Regress SCI on TSIR (path a, Figure 4.3 in Section 4.4.4), because they need to be related (statistically significant) if safety culture really does mediate TSIR.
- Regress AFR on TSIR (path c, Figure 4.3 in Section 4.4.4), because they need to be related (statistically significant) if TSIR could have its influence mediated by another variable.
- Regress AFR on both TSIR and SCI (path b, Figure 4.3 in Section 4.4.4). If safety culture transmits the effect of TSIR on AFR, the regression coefficient for TSIR now is significantly reduced, because its effect is removed by going through the mediator variable.

The results of regression analysis for path a (regress SCI on TSIR) are presented in Tables 5.22 and 5.23. The relationship between SCI and TSIR is expressed by means of the following equation (Eq. 5.2):

$$\mathrm{SCI} = 3.155 + 0.208 \cdot \mathrm{TSIR} + \varepsilon \quad \text{……………………………………………….}\textit{(Eq. 5.2)}$$

where ε is the residual term. The effect of TSIR on SCI is significant (*β=0.316, p<0.05).*

Table 5.22 Model Summary (Regress SCI on TSIR)

Model Summary	
R	0.316
R^2	0.1
Adjusted R^2	0.08
Standard Error of the Estimate	0.171
F	5.009
Sig.	0.03

Table 5.23 Model Coefficients (Regress SCI on TSIR)

	Unstandardized Coefficients		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*β*		
Constant	3.155	0.192		16.403	0.000
TSIR	0.208	0.063	0.316	2.238	0.030

Tables 5.24 and 5.25 show the results of regressing AFR on TSIR (path c). The regression equation is expressed as follows (Eq. 5.3):

$AFR = 62.394 - 20.1 \cdot TSIR + e$ ……………...…………………………….(Eq. 5.3)

where *e* is the residual term. *TSIR* is significantly related to AFR (*β=-0.436, p<0.01).*

Table 5.24: Model Summary (Regress AFR on TSIR)

Model Summary	
R	0.436
R^2	0.19
Adjusted R^2	0.172
Standard Error of the Estimate	11.40
F	10.534
Sig.	0.002

Table 5.25 Model Coefficients (Regress AFR on TSIR)

	Unstandardized Coefficients		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*β*		
Constant	62.394	12.831		4.863	0.000
TSIR	-20.100	6.193	-0.436	-3.246	0.002

For the last step, SCI was added to the Eq. 5.3. A regression analysis with both SCI and TSIR for predicting AFR was conducted and the results are presented in Tables 5.26 and 5.27. The regression equation is then expressed as follows (Eq.5.4):

$$AFR = 136.672 - 15.208 \cdot TSIR - 23.544 \cdot SCI + \varepsilon \quad \text{……………….……(Eq. 5.4)}$$

where ε is the residual term. It was found that, in this equation, although both the effects of SCI (*β=-0.335, p<0.05)* and TSIR (*β=-0.330, p<0.05)* on AFR were significant, the effect of TSIR on AFR shrank upon the addition of SCI to the model. Based on the conditions in which mediation can be said to occur (see Section 4.4.4), it could be inferred that the effects of TSIR to AFR are partially mediated by SCI.

Table 5.26 Model Summary (Regress AFR on TSIR and SCI)

Model Summary	
R	0.539
R^2	0.291
Adjusted R^2	0.258
Standard Error of the Estimate	10.787
F	9.012
Sig.	0.001

Table 5.27 Model Coefficients (Regress AFR on TSIR and SCI)

	Unstandardized Coefficients		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*β*		
Constant	136.672	32.075		4.261	0.000
TSIR	-15.208	6.177	-0.330	-2.462	0.018
SCI	-23.544	9.410	-0.335	-2.502	0.016

Furthermore, Sobel Test (see Section 4.4.4) was carried out to determine the significance of the indirect effect by the mediator (SCI). The result of the Sobel Test presented in Table 5.28 shows that the mediated/indirect effects by SCI are significant (p<0.05). Based on the results of Baron and Kenny (1986) method and Sobel Test, it could be concluded that the effects of TSIR on AFR are partially transmitted by SCI. There are both direct and indirect effects of total safety investments to AFR.

Table 5.28 Results of Sobel Test (Mediated effect of TSIR on AFR)

Input				**Results**		
a	b	s_a	s_b	Test statistic	Std. Error	p-value
0.208	-23.544	0.063	9.41	-1.994	2.456	0.046

In summary, accident frequency rate of building projects was found to be negatively related to the level of total safety investments. The relationship between the level of total safety investments and accident frequency rate is not moderated by project hazard level. As there is no correlation between TSIR and PHI (see Figure 5.14), the effects of total safety investments to accident frequency rate are not mediated project hazard level.

As for project safety culture, the results also show that it does not moderate the effects of total safety investments on accident frequency rate. Nonetheless, the results of mediation analysis indicate that variations in levels of total safety investments account for variations in the levels of safety culture and that variations in the levels of safety culture account for variations in the accident frequency rate. Both direct and indirect effects between the level of total safety investments and accident frequency rate were detected. Total safety investment was found to have its impact on accident frequency rate by partially going through the mediator, safety culture. In-depth discussions about these results were developed in Section 6.3.

5.3.3 Effects of basic safety investments on safety performance

Having examined the effects of total safety investments on safety performance, this section examines the effects of basic safety investments on safety performance of building projects.

The results of bivariate correlation analysis (see Figure 5.14 in Section 5.3.1) show that BSIR is negatively correlated to AFR (r = -0.282, $p < 0.05$), while it has no significant ($p > 0.05$) correlation with ASR (r = -0.099). Moderated regression analysis (see Section 4.4.3) was used to test whether the effect of basic safety investments on AFR is moderated by safety culture level (see Section 5.3.3.1) and project hazard level (see Section 5.3.3.2) of building projects. As shown in Figure 5.14 (see Section 5.3.1), BSIR has no significant ($p > 0.05$) correlations with SCI (r =

0.23) and PHI (*r* = -0.007). This result indicates that the effect of BSIR to AFR is not mediated by SCI and PHI. Thus, mediation analysis was not conducted in this section.

Before the regression analysis was performed, the assumptions (refer to Section 4.4.2 for details) of linearity, homoscedasticity and normality are checked by visually examining the scatterplots (see Figure 5.14) and histograms (see Figures 5.7, 5.9, 5.11 and 5.12). The examination of scatterplots (see Figure 5.14) did not reveal any apparent violations of linearity and homoscedasticity assumptions. The histograms of AFR (see Figure 5.7), BSIR (see Figure 5.9), SCI (see Figure 5.12) and PHI (see Figure 5.11) indicate that BSIR, SCI and PHI meet the assumption of normality, while AFR shows a positively skewed distribution. However, for the comparability in the interpretation phase and robustness of the regression techniques, transformations are not deemed necessary.

The scatter plots were used to explore the patterns of the relationships between BSIR and AFR. To explore whether the patterns are different under different project hazard and safety culture conditions, five scattergrams are presented: (1) plotting the scatters using all cases (Figure 5.20); (2) plotting the scatters under higher project hazard level (i.e. when PHI >mean = 2.90) (see Figure 5.21); (3) plotting the scatters under lower project hazard level (i.e. when PHI ≤ 2.90) (see Figure 5.22); (4) plotting the scatters under higher safety culture level (i.e. when SCI > mean= 3.58) (see Figure 5.23); and (5) plotting the scatters under lower safety culture level (i.e. when SCI ≤ 3.58) (see

Figure 5.24).

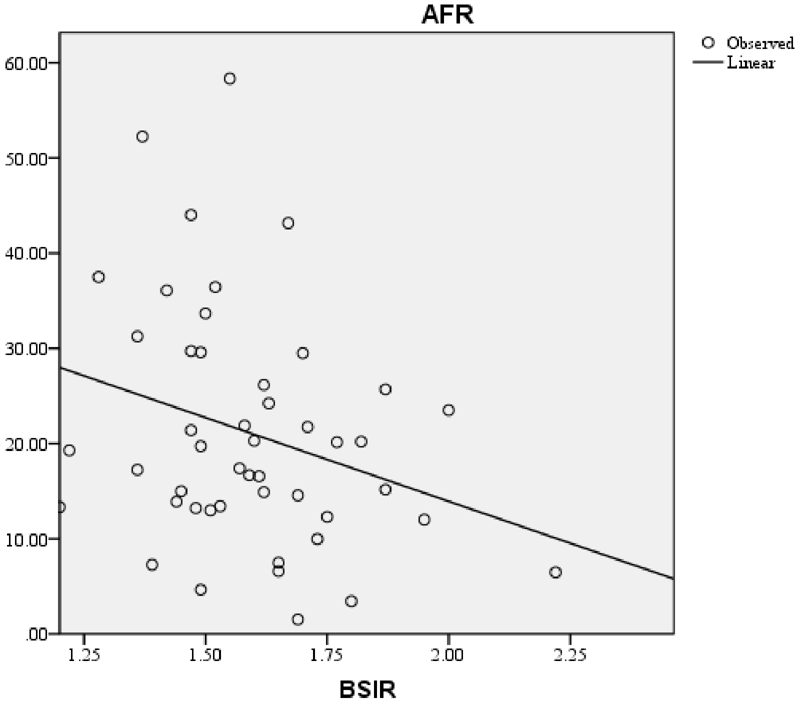


Figure 5.20: Plotting AFR on BSIR (All Cases)

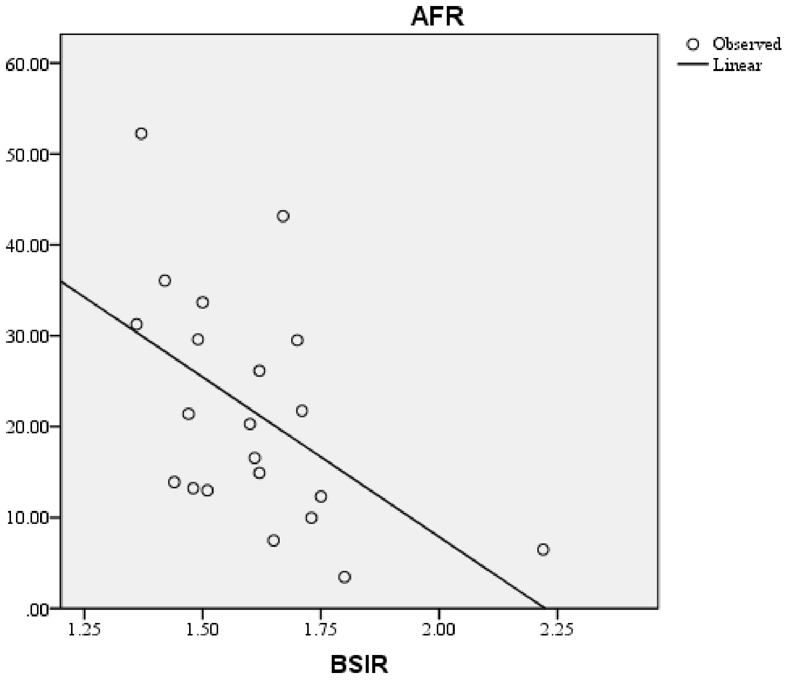


Figure 5.21: Plotting AFR on BSIR (when PHI >2.90)

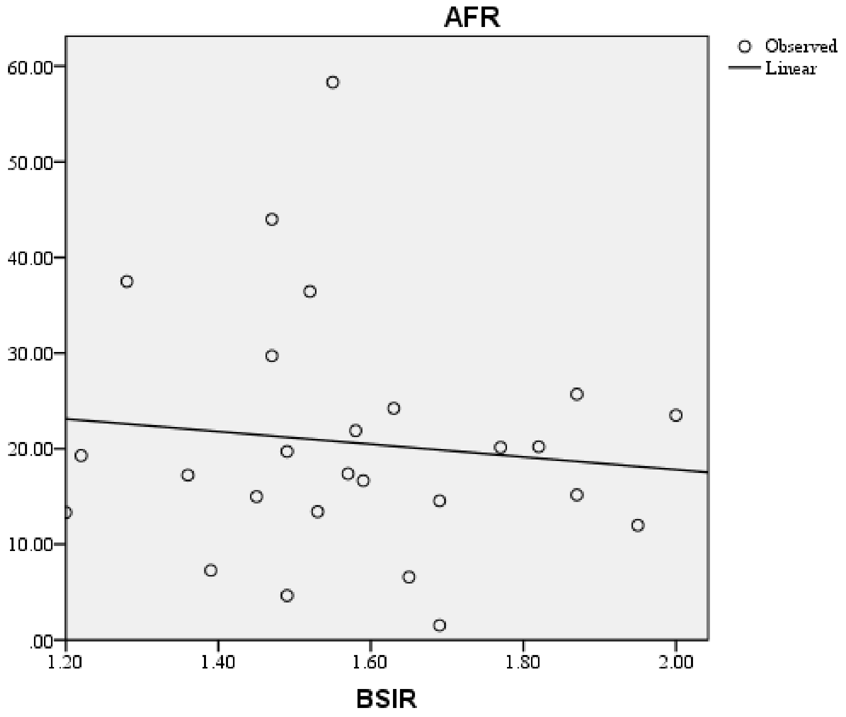


Figure 5.22: Plotting AFR on BSIR (when PHI ≤ 2.90)

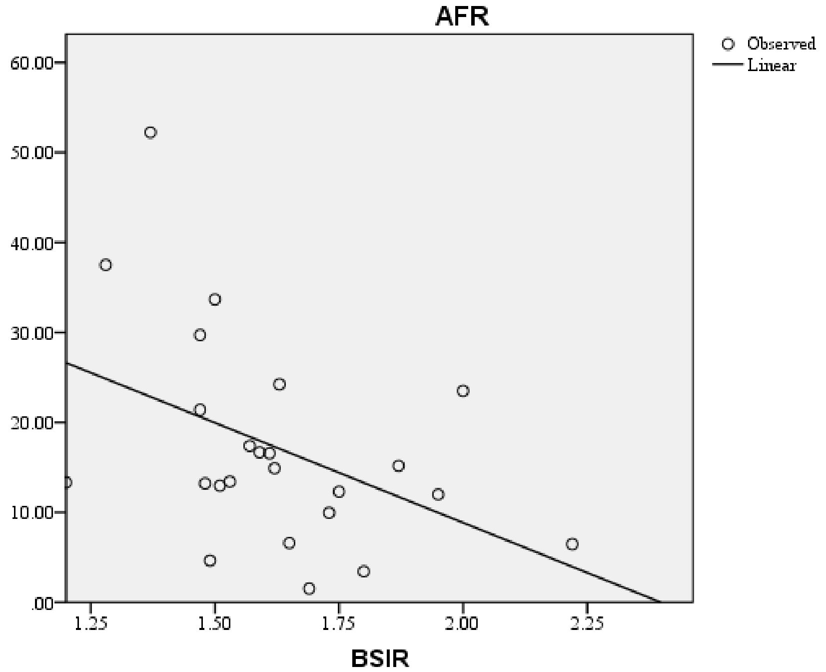


Figure 5.23: Plotting AFR on BSIR (when SC > 3.58)

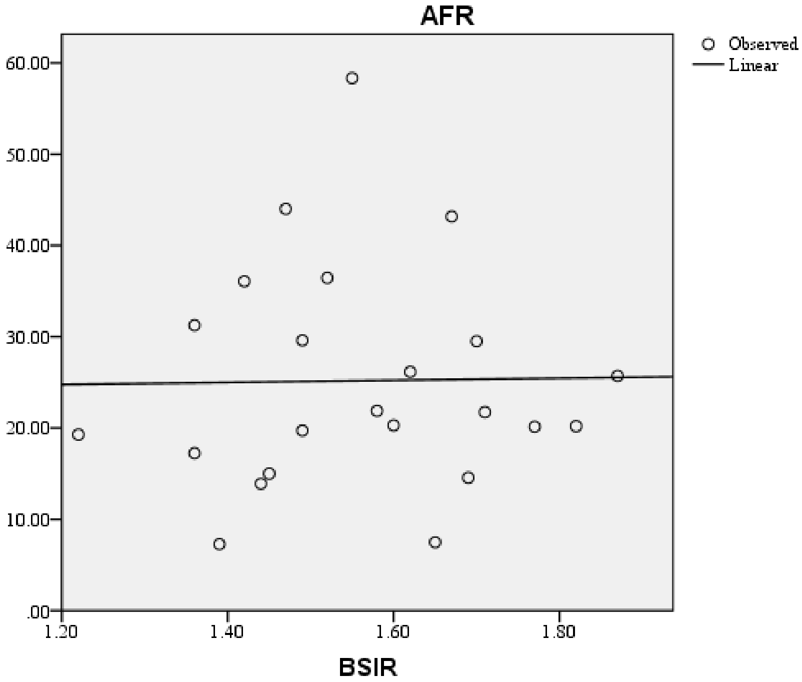


Figure 5.24: Plotting AFR on BSIR (when SCI ≤ 3.58)

From the Figures 5.20, 5.21, 5.22, 5.23 and 5.24, a general negative tendency of the relationship between AFR and BSIR is indicated. Furthermore, by visually examining the estimated relationship between AFR and BSIR under different PHI and SCI levels, the slope of estimated lines looks different under different project hazard and safety culture levels. The effect of BSIR on AFR seems stronger when SCI and PHI are higher. The following sections (Sections 5.3.3.1 and 5.3.3.2) use the moderation analysis to further explore the potential relationship between AFR and BSIR.

5.3.3.1 Moderated effects (interaction effects) of basic safety investments and safety culture on AFR

Following the procedures for running the moderated regression analysis that have been described in Section 4.4.3, the moderated regression model postulates that AFR is a linear function of BSIR, SCI, and the interaction of BSIR and SCI (BSIR * SCI) (Eq. 5.5).

$$AFR = \beta_0 + \beta_1 \bullet BSIR + \beta_2 \bullet SCI + \beta_3 \bullet BSIR \bullet SCI + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.5)}$$

Where the intercept β_0 and the slopes (β_1, β_2, β_3) are unknown constants, ε is a random error component.

The results of regression analysis are presented in Tables 5.29 and 5.30. It was shown that the interaction term between BSI and SCI (BSI * SCI) has a significant effect on AFR ($p < 0.05$). The R^2 contribution of the interactive effect on AFR is 6.3%.

*Table 5.29: Model Summary (Regress AFR on BSIR, SCI and BSIR *SCI)*

Model Summary	
R	0.539
R^2	0.29
Adjusted R^2	0.24
Standard Error of the Estimate	10.92
F	5.85
Sig.	0.002
R^2 Contribution of the Product Term	0.063

*Table 5.30: Model Coefficients (Regress AFR on BSIR, SCI and BSIR * SCI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	21.82	1.63	13.34	0.000
Centered BSIR	-5.72	8.83	-0.64	0.520
Centered SCI	-30.51	9.38	-3.25	0.002
Product term	-90.27	46.31	-1.98	0.047

Following the interpretation method of interactions suggested by Aiken and West (1991) and Cohen *et al.* (2003) (see Section 4.4.3), three simple regression equations for AFR on centered BSIR at three values of centered SCI (+1 Std. Dev., mean, and -1

Std. Dev.) were summarized in Table 5.31, and the lines were plotted in Figure 5.25.

Table 5.31: Summary of Simple Regression Equations for AFR on Centered BSIR at Three Values of Centered SCI

	Simple regression line 1 (SCI $_{+1\text{ Std. Dev.}}$)	*Simple regression line 2* (SCI $_{\text{mean}}$)	*Simple regression line 3* (SCI $_{-1\text{ Std. Dev.}}$)
Moderator	SCI	SCI	SCI
Level of the Moderator	+1 Std. Dev.	Mean	-1 Std. Dev
Simple slope	-21.81*	-5.72	10.36
Intercept	16.39	21.82	27.26
Std. Error of simple slope	9.68	21.82	14.08
Degree of Freedom	43	43	43
T	-2.25	-0.64	0.74
Sig. of simple slope	0.015	0.26	0.23

* $p<0.05$

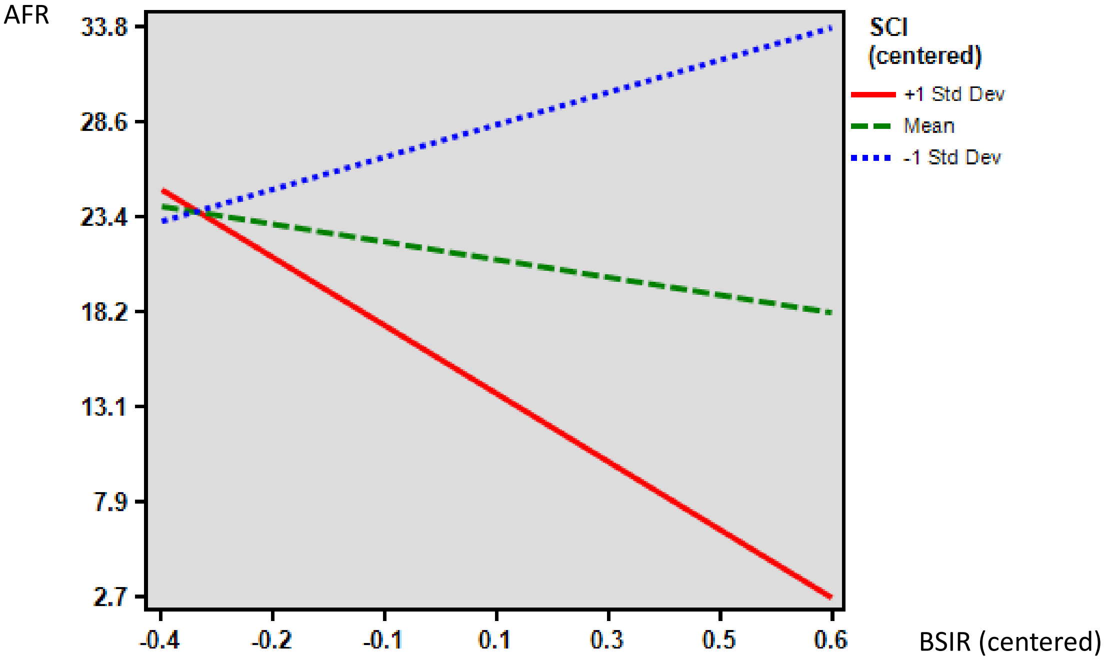


Figure 5.25: Simple Regression Lines for AFR on Centered BSIR at Three Values of Centered SCI.

As shown in Table 5.31, the effect of BSIR on AFR is negative and significant when

SCI is high (SCI=+1 Std. Dev.), but no longer significant when SCI is at mean level (SCI=mean value) or low (SCI=-1 Std. Dev.). It was noteworthy that the simple slope of the simple regression line 3 (SCI=-1 Std. Dev.) is positive (10.36), which means that when the level of safety culture is low, the relationship between BSIR and AFR becomes positive. BSIR plays a positive role in accident prevention of building projects under high safety culture environment, while it plays a negative role under low safety culture environment. This finding is not consistent with the popular assumption that the higher the safety investment is, the better the safety performance will be (Levitt, 1975; Laufer, 1987; Brody *et al.*, 1990; Hinze, 2000). This could perhaps explain why there were discrepancies on the relationship between safety investments and safety performance in previous studies, such as Crites (1995) and Tang *et al.* (1997). More in-depth discussions about this finding are provided in Section 6.4.

5.3.3.2 Moderated effects (interaction effects) of basic safety investments and project hazard level on AFR

Moderated regression analysis (see Section 4.4.3) was also used to test the moderated effects (interactive effects) of basic safety investments and project hazard level on AFR. The regression model postulates that AFR is a linear function of BSIR, PHI, and the interaction of BSIR and PHI (BSIR * PHI) (Eq. 5.6).

$$AFR = \beta_0 + \beta_1 \bullet BSIR + \beta_2 \bullet PHI + \beta_3 \bullet BSIR \bullet PHI + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.6)}$$

Where the intercept β_0 and the slopes (β_1, β_2, β_3) are unknown constants, ε is a random error component.

The results of regression analysis are presented in Tables 5.32 and 5.33. Table 5.33 shows that the interaction term between BSIR and PHI (BSIR * PHI) has a significant effect on AFR (p <0.05). The R^2 contribution of the interactive effects of BSIR and PHI on AFR is 8.6%.

*Table 5.32: Model Summary (Regress AFR on BSIR, PHI and BSIR * PHI)*

Model Summary	
R	0.43
R^2	0.19
Adjusted R^2	0.13
Standard Error of the Estimate	11.67
F	3.33
Sig.	0.028
R^2 Contribution of the Product Term	0.086

*Table 5.33: Model Coefficients (Regress AFR on BSIR, PHI and BSIR * PHI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	21.07	1.70	12.38	0.000
Centered BSIR	-20.62	8.70	-2.37	0.022
Centered PHI	3.26	3.18	1.03	0.309
Product term	-39.06	18.30	-2.13	0.038

Following the interpretation method of interactions suggested by Aiken and West (1991) and Cohen *et al.* (2003) (see Section 4.4.3), three simple regression equations for AFR on centered BSIR at three values of centered PHI (+1 Std. Dev., mean, and -1 Std. Dev.) were summarized in Table 5.34, and the lines were plotted in Figure 5.26.

Table 5.34: Summary of Simple Regression Equations for AFR on Centered BSIR at Three Values of Centered PHI

	Simple regression line 1 (PHI $_{+1\ Std.\ Dev.}$)	*Simple regression line 2 (PHI $_{mean}$)*	*Simple regression line 3 (PHI $_{-1\ Std.\ Dev.}$)*
Moderator	PHI	PHI	PHI
Level of the Moderator	+1 Std. Dev.	Mean	-1 Std. Dev
Simple slope	-41.75**	-20.62*	0.51
Intercept	22.84	21.07	19.30
Std. Error of simple slope	14.23	8.70	12.04
Degree of Freedom	43	43	43
T	-2.25	-2.37	0.04
Sig. of simple slope	0.003	0.011	0.483

* $p<0.05$; ** $p<0.01$

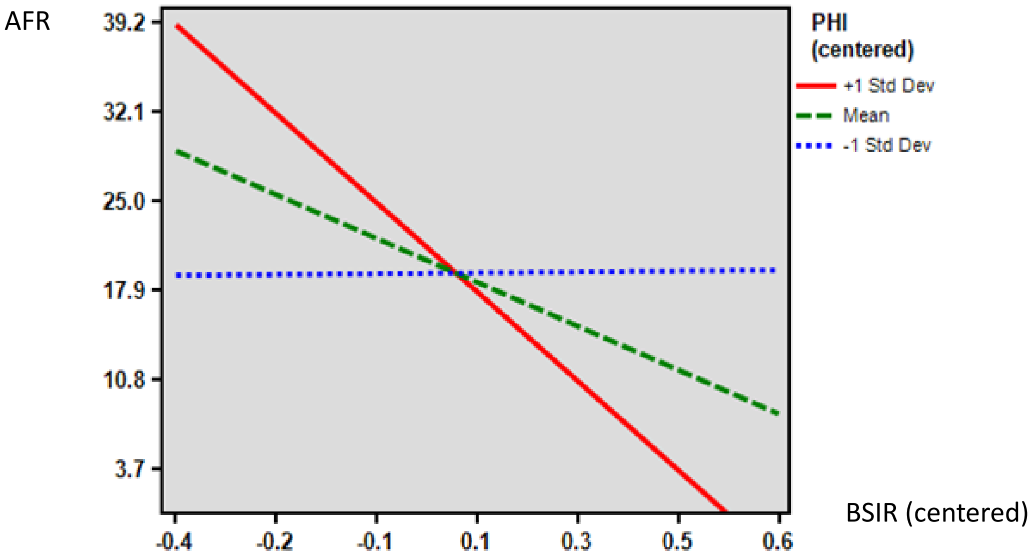


Figure 5.26: Simple Regression Lines for AFR on Centered BSIR at Three Values of Centered PHI

As indicated in Table 5.34, the effect of BSIR on AFR is negative and significant when PHI is high (PHI= +1 Std. Dev) and at mean level (PHI= mean value), but no longer significant when PHI is low (PHI= -1 Std. Dev). The variance of the simple slopes for AFR on BSIR at different levels of PHI indicates a stronger positive effect of BSIR on accident prevention under higher project hazard level. More discussions about this result are provided in Section 6.4.

In summary, the results of this section show that the relationship between BSIR and AFR is moderated by both SCI and PHI. This finding indicates that the effect of basic safety investments on AFR does not hold constant for all building projects. Basic safety investments have stronger positive effect on the reduction of accident frequency rate for those projects with higher project hazard level and higher safety culture level. Please refer to Section 6.4 for more in-depth discussions about this finding.

5.3.4 Effects of voluntary safety investments on safety performance

Having examined the effects of basic safety investments on safety performance, this section examines the effects of voluntary safety investments on safety performance of building projects.

The results of bivariate correlation analysis (see Figure 5.14 in Section 5.3.1) show that VSIR is significantly correlated to AFR ($r = -0.539$, $p < 0.05$), while it is not significantly ($p > 0.05$) correlated with ASR ($r = -0.109$). This indicates that with the increase of VSIR, the frequency of construction accidents tends to be reduced. Moderated regression analysis (see Section 4.4.3) was used to test whether the effect of voluntary safety investments on AFR is moderated by safety culture level (see Section 5.3.4.1) and project hazard level (see Section 5.3.4.2) of building projects. As discussed in Section 5.3.1, the effect of voluntary safety investments on safety performance is likely to be mediated by safety culture level. The mediation effects were tested using the regression methods suggested by Baron and Kenny (1986) (see Section 4.4.4), and the results were presented in Section 5.3.4.3.

Before the regression analyses are performed, the basic assumptions (refer to Section 4.4.2 for details) underlying regression analysis are checked. Examination of the scatterplots (Figure 5.14) does not reveal either apparent nonlinear relationships or a dramatically different type of dot cluster. The histograms of AFR (see Figures 5.7), VSIR (see Figure 5.10), PHI (see Figure 5.11) and SCI (see Figure 5.12) indicate that the variables PHI and SCI have an approximate normal distribution, whilst variables AFR and VSIR exhibit positively skewed distribution. As regression analysis has been shown to be quite robust even when the normality assumptions are violated, then the original variables may be preferred for the comparability in the interpretation phase (Hair *et al.*, 1998). Thus, transformations are not deemed necessary. The scatter plots were used to explore the patterns of the relationships between VSIR and AFR. To explore whether the patterns are different under different project hazard and safety culture conditions, five scattergrams are presented: (1) plotting the scatters using all cases (Figure 5.27); (2) plotting the scatters under higher project hazard level (i.e. when PHI >mean = 2.90) (see Figure 5.28); (3) plotting the scatters under lower project hazard level (i.e. when PHI ≤ 2.90) (see Figure 5.29); (4) plotting the scatters under higher safety culture level (i.e. when SCI > mean= 3.58) (see Figure 5.30); and (5) plotting the scatters under lower safety culture level (i.e. when SCI ≤ 3.58) (see Figure 5.31).

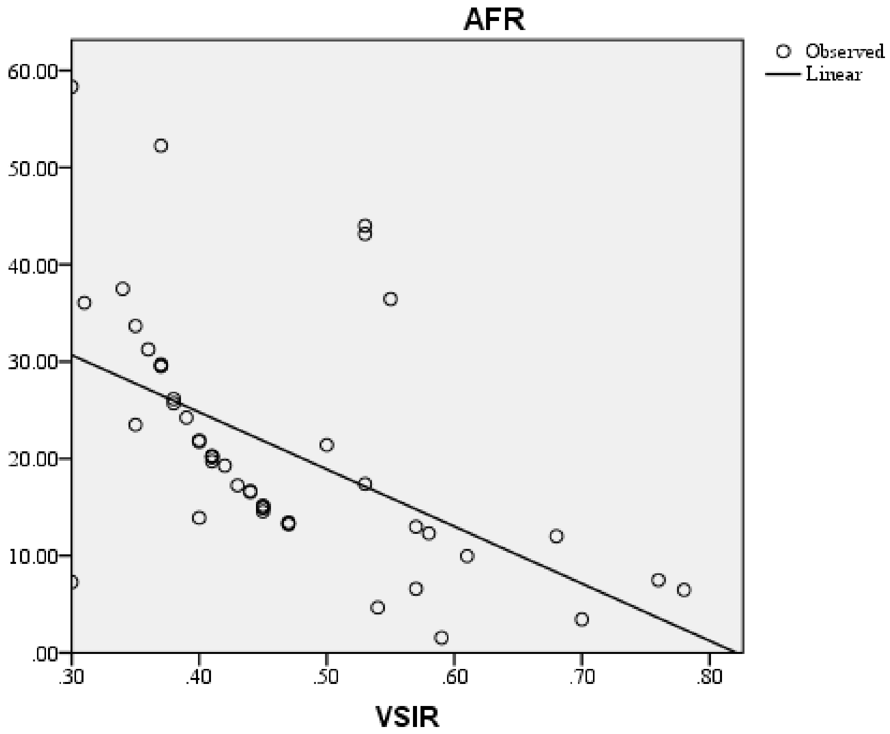


Figure 5.27: Plotting AFR on VSIR (All Cases)

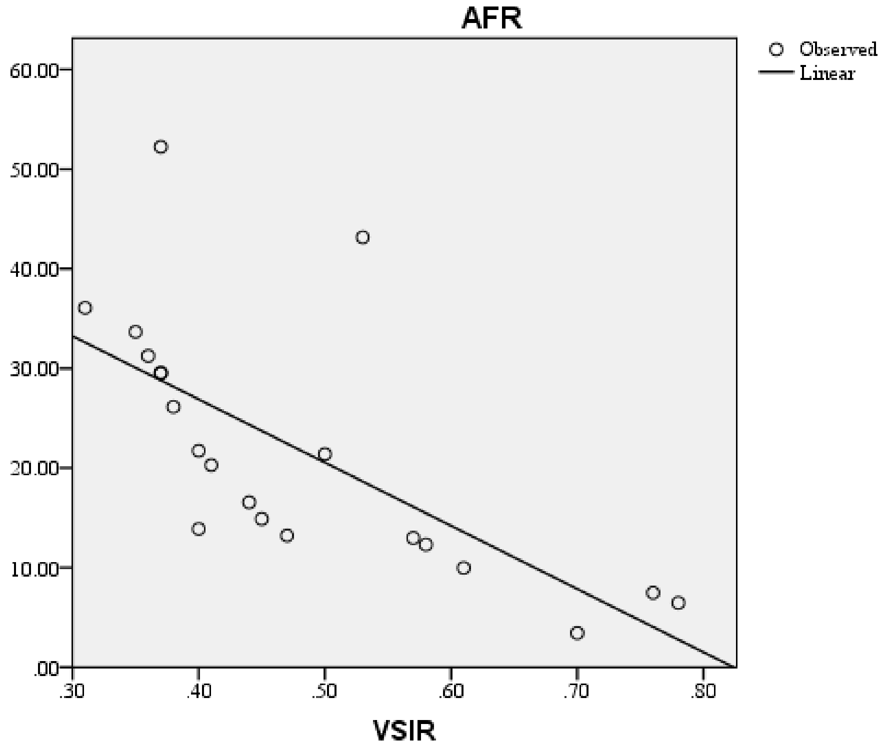


Figure 5.28: Plotting AFR on VSIR (when PHI>2.90)

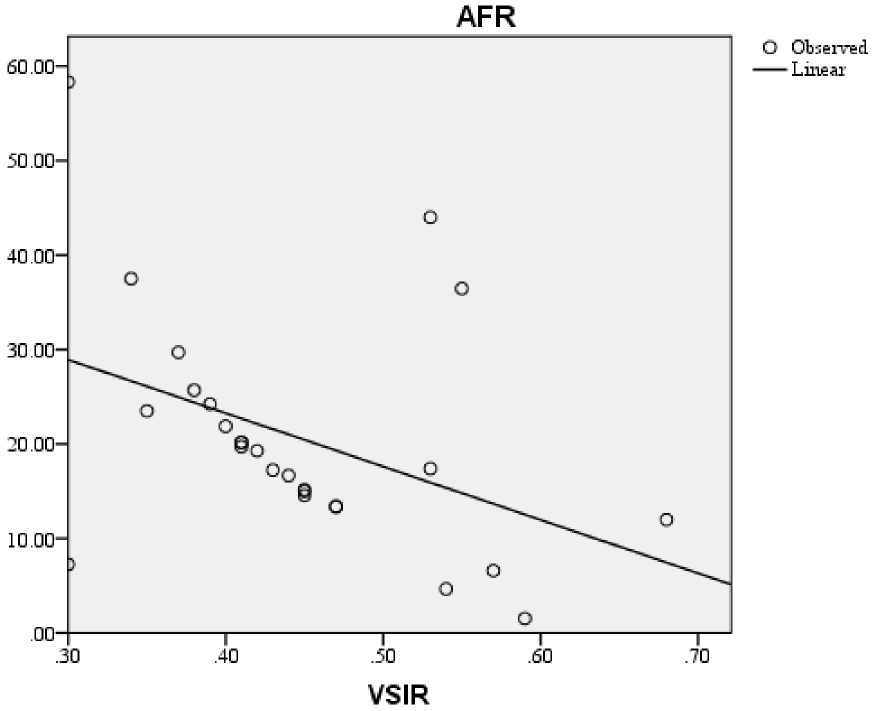


Figure 5.29: Plotting AFR on VSIR (when PHI≤2.90)

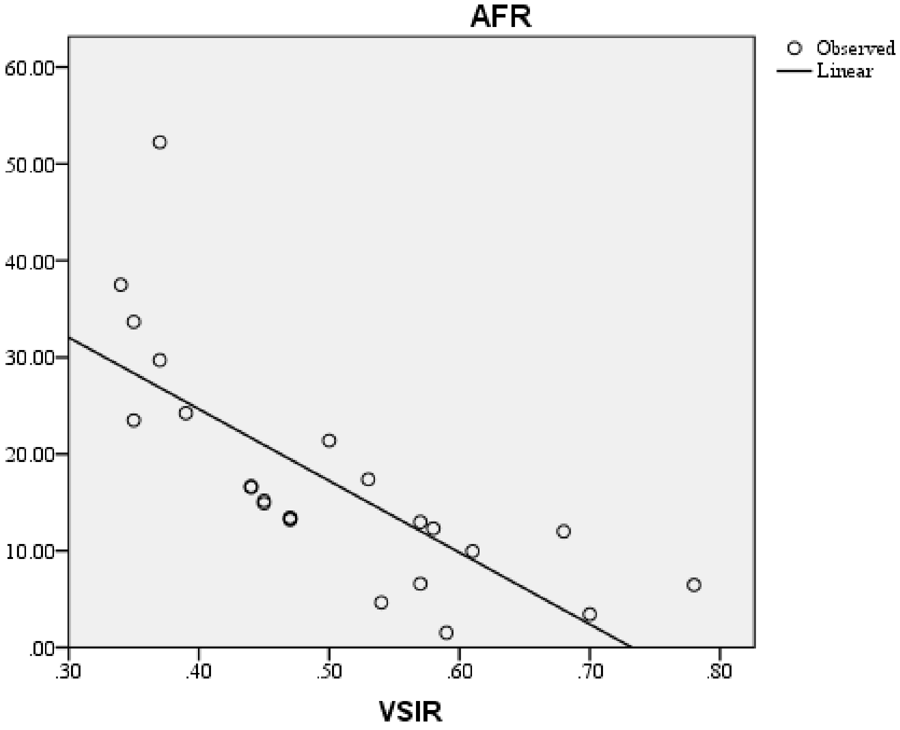


Figure 5.30: Plotting AFR on VSIR (when SCI>3.58)

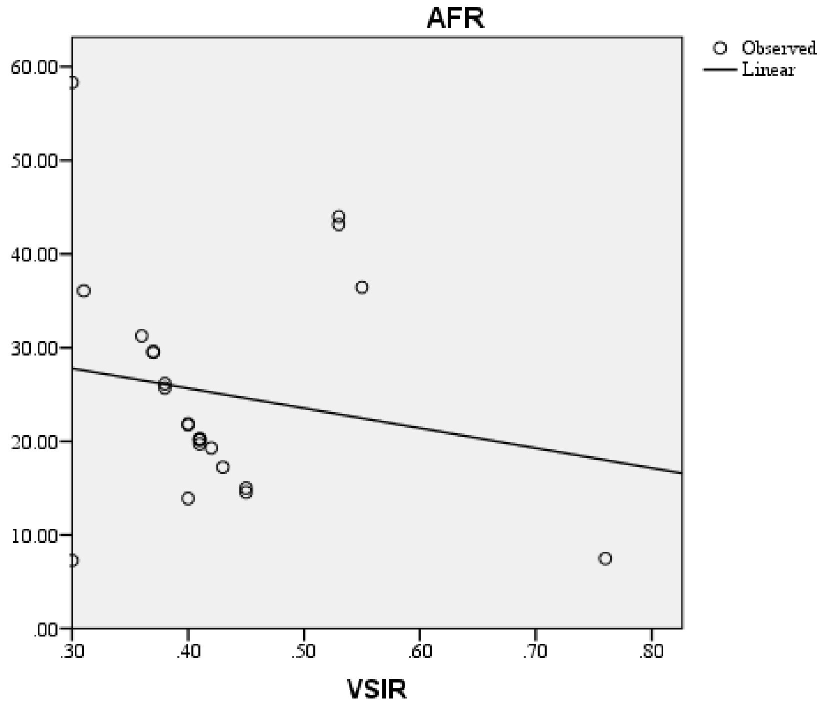


Figure 5.31: Plotting AFR on VSIR (When SCI ≤3.58)

From the Figures 5.27, 5.28, 5.29, 5.30 and 5.31, a general negative tendency of the relationship between AFR and VSIR is indicated. Furthermore, it seems that the relationship between VSIR and AFR does not show significant differences under different project hazard levels; while this relationship looks different under different safety culture levels. The following sections (Sections 5.3.4.1, 5.3.4.2 and 5.3.4.3) uses the moderation and mediation analyses to further explore the potential relationship between AFR and TSIR.

5.3.4.1 Moderated effects (interaction effects) of voluntary safety investments and safety culture level on AFR

To test the moderated effects (interaction effects) of VSIR and SCI on AFR, the regression model postulates that AFR is a linear function of VSIR, SCI, and the interaction of VSIR and SCI (VSIR * SCI) (Eq. 5.7).

$$AFR = \beta_0 + \beta_1 \bullet VSIR + \beta_2 \bullet SCI + \beta_3 \bullet VSIR \bullet SCI + \varepsilon \text{ ……………………… (Eq. 5.7)}$$

Where the intercept β_0 and the slopes (β_1, β_2, β_3) are unknown constants, ε is a random error component.

The results of regression analysis are presented in Tables 5.35 and 5.36. It is shown that the interaction term between VSIR and SCI (VSIR * SCI) does not have a significant effect on AFR ($p > 0.05$). The R^2 contribution of the interactive effect on AFR is only 2.02%. Thus, the effect of VSIR on AFR is not moderated by the level of safety culture of the project.

*Table 5.35: Model Summary (Regress AFR on VSIR, SCI and VSIR * SCI)*

Model Summary	
R	0.619
R^2	0.383
Adjusted R^2	0.340
Standard Error of the Estimate	10.177
F	8.89
Sig.	0.000
R^2 Contribution of the Product Term	0.020

*Table 5.36: Model Coefficients (Regress AFR on VSIR, SCI and VSIR * SCI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	21.68	1.56	13.85	0.000
Centered VSIR	-43.95	14.37	-3.05	0.003
Centered SCI	-18.66	9.06	-2.05	0.045
Product term	-84.74	71.46	-1.18	0.241

5.3.4.2 Moderated effects (interaction effects) of voluntary safety investments and project hazard level on AFR

To test the moderated effects (interaction effects) of VSIR and PHI on AFR, the regression model postulates that AFR is a linear function of VSIR, PHI, and the interaction of VSIR and PHI (VSIR* PHI) (Eq. 5.8).

$$AFR = \beta_0 + \beta_1 \bullet VSIR + \beta_2 \bullet PHI + \beta_3 \bullet VSIR \bullet PHI + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.8)}$$

Where the intercept β_0 and the slopes (β_1, β_2, β_3) are unknown constants, ε is a random error component.

The results of regression analysis are presented in Tables 5.37 and 5.38. As shown in Table 5.38, the *t*-value for the coefficient of the product term is -0.06 with an associated probability of 0.948, thus it is possible that the regression coefficient has arisen by sampling error. In addition, the R^2 contribution of the interactive effect of VSIR and PHI on AFR was found to be quite low (0.01%). Therefore, the effect of VSIR on AFR is not moderated by the project hazard level.

*Table 5.37: Model Summary (Regress AFR on VSIR, PHI and VSIR * PHI)*

Model Summary	
R	0.572
R^2	0.327
Adjusted R^2	0.280
Standard Error of the Estimate	10.626
F	6.97
Sig.	0.001
R^2 Contribution of the Product Term	0.0001

*Table 5.38: Model Coefficients (Regress AFR on VSIR, PHI and VSIR * PHI)*

Model	*B*	*Std. Error*	*T*	*Sig.*
Constant	21.10	1.55	13.57	0.000
Centered VSIR	-59.96	14.63	-4.09	0.000
Centered PHI	4.40	3.00	1.46	0.149
Product term	-1.94	29.62	-0.06	0.948

5.3.4.3 Mediation effects of voluntary safety investments on AFR

Mediated regression was carried out to test whether the effect of VSIR (independent variable) on AFR (dependent variable) is mediated /transmitted by SCI (mediator). Following the steps to test the mediation effects that were described in Section 4.4.4, regression analyses for path a, b, and c were conducted.

The results of regression analysis for path a (regress SCI on VSI) are presented in Table 5.39 and Table 5.40. The relationship between SCI and VSI is expressed by means of the following equation (Eq. 5.9):

$$SCI = 3.332 + 0.539 \bullet VSIR + \varepsilon \quad \text{...(Eq. 5.9)}$$

where ε is the residual term. The effect of VSIR on SCI is significant ($\beta=0.347, p<0.05$).

Table 5.39: Model Summary (Regress SCI on VSIR)

Model Summary	
R	0.347
R^2	0.12
Adjusted R^2	0.101
Standard Error of the Estimate	0.169
F	6.142
Sig.	0.017

Table 5.40: Model Coefficients (Regress SCI on VSIR)

	Unstandardized Coefficients		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*β*		
Constant	3.332	0.104		32.186	0.000
VSIR	0.539	0.217	0.347	2.478	0.017

Table 5.41 and Table 5.42 describe the results of regressing AFR on VSIR (path c). The regression equation is expressed as Eq. 5.10.

$$AFR = 48.34 - 58.89 \cdot VSIR + \varepsilon \quad \text{……………...………………………(Eq. 5.10)}$$

where ε is the residual term. VSIR is significantly related to AFR ($\beta = -0.539$, $p<0.01$).

Table 5.41: Model Summary (Regress AFR on VSIR)

Model Summary	
R	0.539
R^2	0.29
Adjusted R^2	0.275
Standard Error of the Estimate	10.67
F	18.41
Sig.	0.000

Table 5.42: Model Coefficients (Regress AFR on VSIR)

	Unstandardized Coefficients		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*β*		
Constant	48.34	6.537		7.395	0.000
VSIR	-58.89	13.726	-0.539	-4.291	0.000

For the last step, SCI was added to Eq. 5.10. A regression analysis with both SCI and VSIR for predicting AFR was conducted and the results were presented in Table 5.43 and Table 5.44. The regression equation is then expressed as Eq. 5.11.

$AFR = 115.56 - 48.03 \bullet VSIR - 20.17 \bullet SCI + \varepsilon$ ....(Eq. 5.11)

where ε is the residual term.

It is found that, in this equation, although both the effects of SCI (β =-0.287) and VSIR (β =-0.439) on AFR are significant (p <0.05), the effect of VSIR on AFR shrinks upon the addition of SCI to the model. Based on the conditions in which mediation can be said to occur (see Section 4.4.4), it could be inferred that the effect of VSIR to AFR is partially mediated by SCI.

Table 5.43: Model Summary (Regress AFR on VSIR and SCI)

Model Summary	
R	0.602
R^2	0.363
Adjusted R^2	0.334
Standard Error of the Estimate	10.224
F	12.53
Sig.	0.000

Table 5.44: Model Coefficients (Regress AFR on VSIR and SCI)

	Unstandardized Coefficients		*Standardized Coefficients*	*t*	*Sig.*
	B	*Std. Error*	*β*		
Constant	115.56	30.70		3.764	0.000
VSIR	-48.03	14.02	-0.439	-3.425	0.001
SCI	-20.17	9.02	-0.287	-2.236	0.030

Furthermore, Sobel Test (see Section 4.4.4) was carried out to determine the significance of the indirect effects by the mediator (SCI). The result of the Sobel Test is presented in Table 5.45. The result shows that the mediated/indirect effect by SCI is significant (p <0.05). Thus, based on the results of Baron and Kenny (1986) method and Sobel Test, it could be concluded that the effects of voluntary safety investments on AFR are partially mediated (transmitted) by safety culture level. There are both direct and indirect effects of voluntary safety investments to AFR.

Table 5.45: Results of Sobel Test (Mediated effect of VSIR on AFR)

Input				**Results**		
a	b	s_a	s_b	Test statistic	Std. Error	p-value
0.539	-30.88	0.217	9.42	-1.98	2.52	0.047

In summary, the results of moderation analysis in Sections 5.3.4.1 and 5.3.4.2 show that the relationship between the level of voluntary safety investments and accident frequency rate is not moderated by project hazard level and safety culture level. Nonetheless, the results of mediation analysis in Section 5.3.4.3 show that the effect of voluntary safety investments on accident frequency rate is partially mediated by safety culture level. This finding suggests that increase in voluntary safety investments may lead to the enhancement of safety culture, which then transmits the effects of voluntary safety investments to the safety performance. Both direct and indirect effects between the level of voluntary safety investments and accident frequency rate were detected. More discussions regarding the effects of voluntary safety investments on safety performance of building projects are provided in Section 6.3.

5.3.5 Moderated effects (interaction effects) of safety culture level and project hazard level on safety performance

Hypothesis 1 (see Section 3.2) of this study posits that safety performance of building projects is determined by the interactions of safety investments, safety culture and project hazard level. Previous sections (Sections 5.3.2, 5.3.3 and 5.3.4) have examined the interactions of safety investments and safety culture level and the interactions of safety investments and project hazard level in determining safety performance of building projects. This section examines the interactions of safety culture level and project hazard level in determining safety performance of building projects. The results of bivariate correlation analysis (see Figure 5.14 in Section 5.3.1) show that SCI is significantly ($p < 0.05$) correlated with both ASR ($r = -0.46$) and AFR ($r = -0.439$) of building projects. It suggests that both ASR and AFR would be reduced with the increase of safety culture level of a building project. Moderated regression analysis (see Section 4.4.3) was conducted to test if the effects of SCI on ASR and AFR are moderated by PHI.

Before the regression analysis was performed, the basic assumptions (refer to Section 4.4.2 for details) underlying regression analysis are checked. Examination of the scatterplots (Figure 5.14) does not reveal either apparent nonlinear relationships or a dramatically different type of dot cluster. The histograms of the variables (refer to Figures 5.6, 5.7, 5.11 and 5.12) indicate that the variables PHI and SCI have an approximate normal distribution, whilst variables AFR and ASR exhibit positively skewed distribution. As regression analysis has been shown to be quite robust even when the normality assumptions are violated, then the original variables may be preferred for the comparability in the interpretation phase (Hair *et al.*, 1998). Thus, transformations are not deemed necessary.

The scatter plots were used to explore the patterns of the relationships between SCI and ASR. To explore whether the patterns are different under different project hazard conditions, three scattergrams are presented: (1) plotting the scatters using all cases (Figure 5.32); (2) plotting the scatters under higher project hazard level (i.e. when PHI >mean = 2.90) (see Figure 5.33); and (3) plotting the scatters under lower project hazard level (i.e. when PHI ≤ 2.90) (see Figure 5.34).

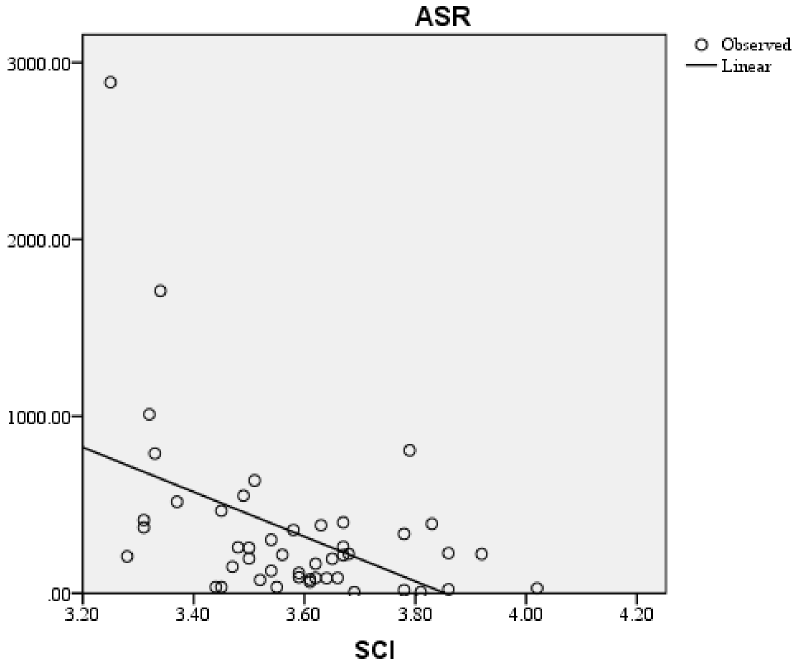


Figure 5.32: Plotting ASR on SCI (All Cases)

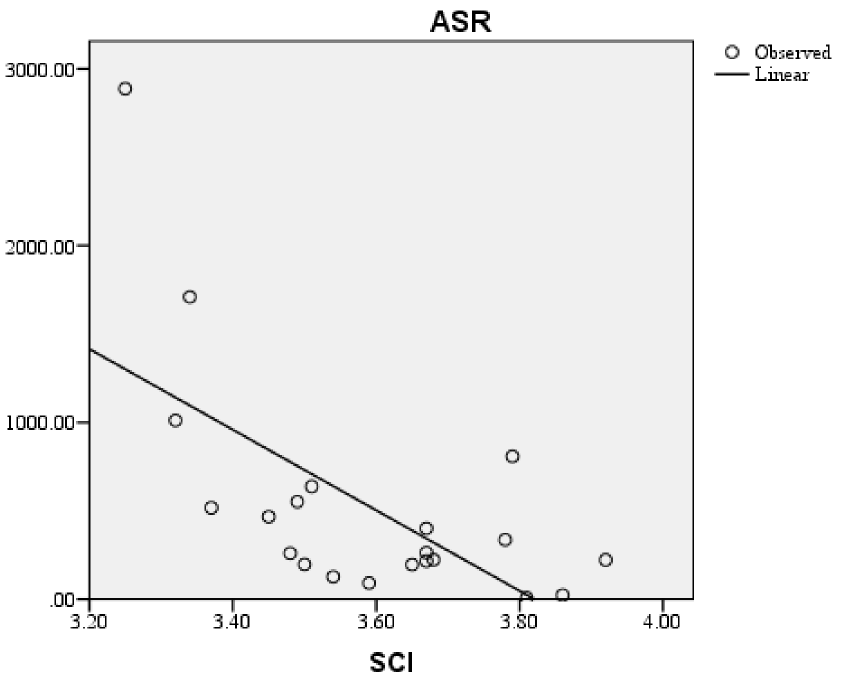


Figure 5.33: Plotting ASR on SCI (When PHI >2.90)

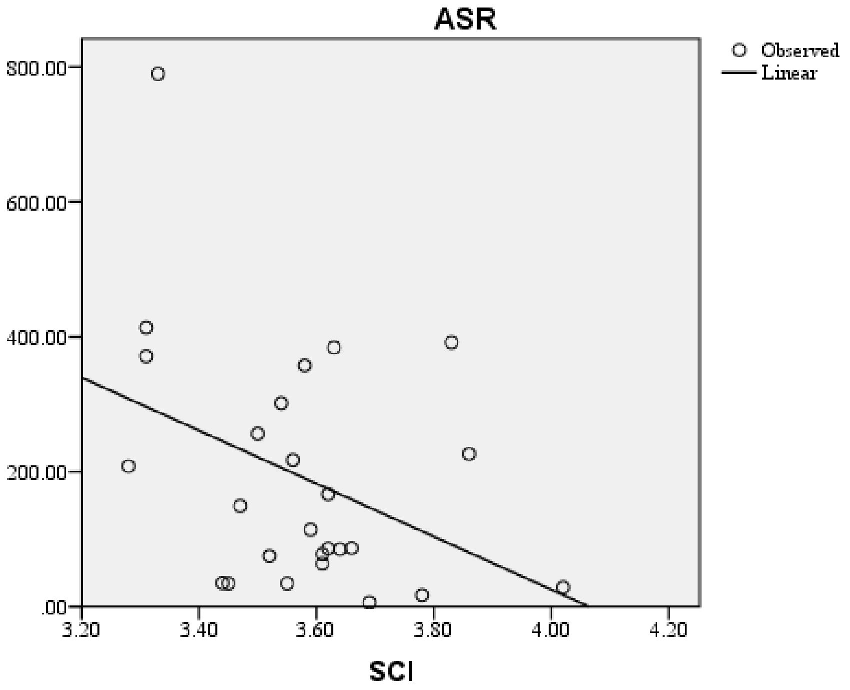


Figure 5.34: Plotting ASR on SCI (When PHI ≤2.90)

Similarly, the scatter plots were also used to explore the patterns of the relationships between SCI and AFR. To explore whether the patterns are different under different project hazard conditions, three scattergrams are presented: (1) plotting the scatters using all cases (Figure 5.35); (2) plotting the scatters under higher project hazard level (i.e. when PHI >mean = 2.90) (see Figure 5.36); and (3) plotting the scatters under lower project hazard level (i.e. when PHI ≤ 2.90) (see Figure 5.37).

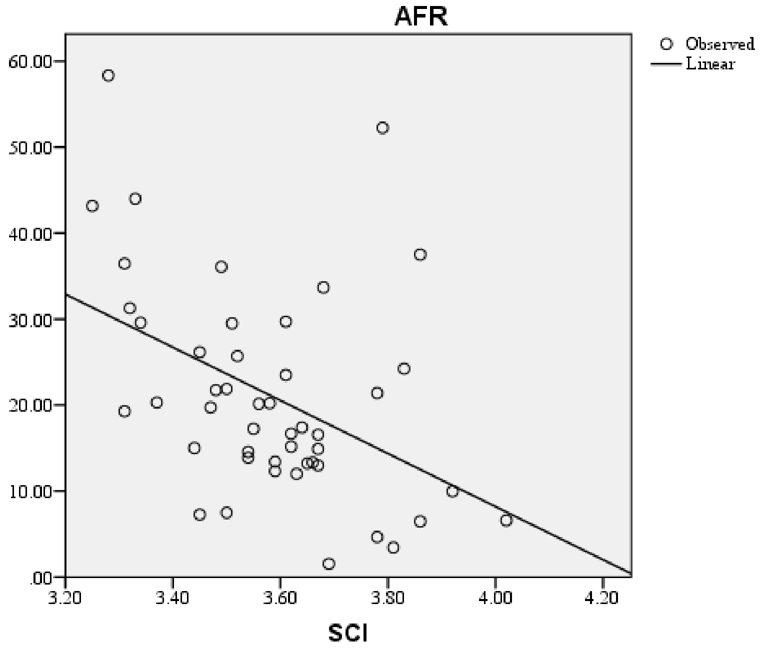


Figure 5.35: Plotting AFR on SCI (All Cases)

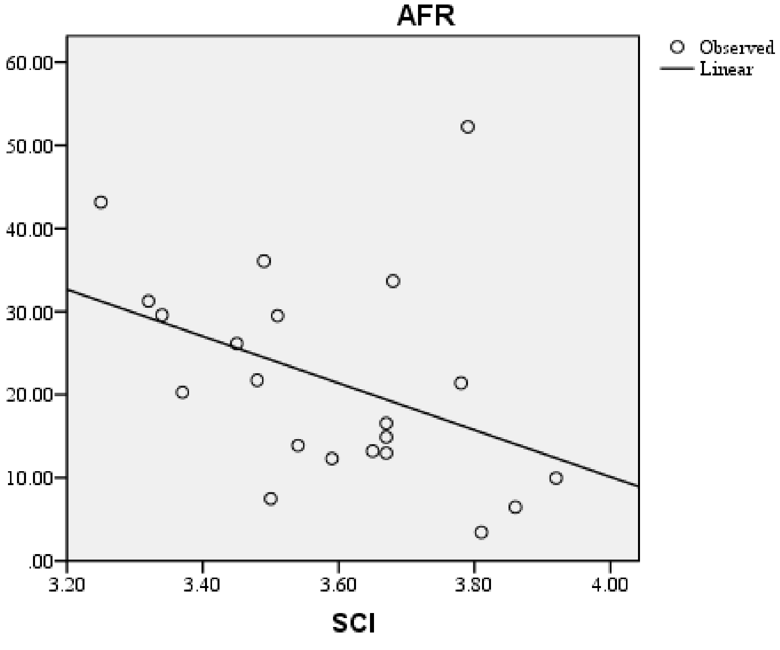


Figure 5.36: Plotting AFR on SCI (When PHI >2.90)

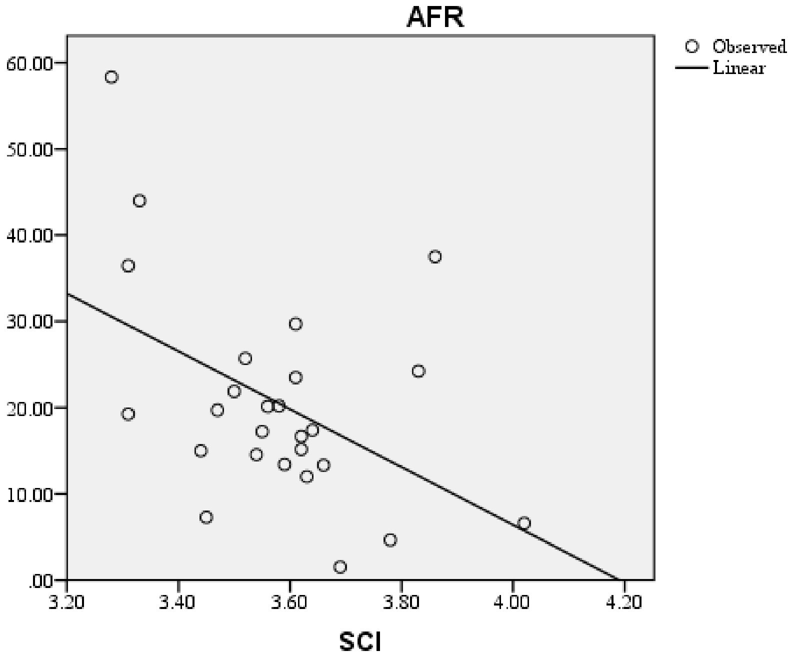


Figure 5.37: Plotting AFR on SCI (When PHI ≤2.90)

5.3.5.1 Moderated effects (interaction effects) of safety culture level and project hazard level on ASR

To test the moderated effects (interaction effects) of SCI and PHI to ASR, the regression model postulates that ASR is a linear function of SCI, PHI, and the interaction of SCI and PHI (SCI * PHI) (Eq. 5.12).

$$ASR = \beta_0 + \beta_1 \cdot SCI + \beta_2 \cdot PHI + \beta_3 \cdot SCI \cdot PHI + \varepsilon \quad \text{……………………..….(Eq. 5.12)}$$

Where the intercept β_0 and the slopes (β_1, β_2, β_3) are unknown constants, ε is a random error component.

The results of regression analysis are presented in Table 5.46 and Table 5.47. The results show that the interaction term between SCI and PHI (SCI * PHI) has a significant effect on ASR ($p < 0.05$). The R^2 contribution of the interactive effect on

AFR is 5.6%.

*Table 5.46: Model Summary (Regress ASR on SCI, PHI and SCI * PHI)*

Model Summary	
R	0.649
R^2	0.421
Adjusted R^2	0.381
Standard Error of the Estimate	385.174
F	10.437
Sig.	0.000
R^2 Contribution of the Product Term	0.056

*Table 5.47: Model Coefficients (Regress ASR on SCI, PHI and SCI * PHI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	350.603	56.30	6.22	0.000
Centered SCI	-1266.88	320.76	-3.95	0.000
Centered PHI	309.64	107.52	2.88	0.006
Product term	-1327.83	648.38	-2.05	0.046

Three simple regression equations for ASR on centered SCI at three values of centered PHI (+1 Std. Dev., mean, and -1 Std. Dev.) were summarized in Table 5.48, and the lines were plotted in Figure 5.38.

Table 5.48: Summary of Simple Regression Equations for ASR on Centered SCI at Three Values of Centered PHI

	Simple regression line 1 (PHI $_{\text{+1 Std. Dev.}}$)	*Simple regression line 2 (PHI $_{\text{mean}}$)*	*Simple regression line 3 (PHI $_{\text{-1 Std. Dev.}}$)*
Moderator	PHI	PHI	PHI
Level of the Moderator	+1 Std. Dev.	Mean	-1 Std. Dev
Simple slope	-1985.27**	-1266.88**	-548.50
Intercept	518.12	350.60	183.08
Std. Error of simple slope	452.53	320.76	497.08
Degree of Freedom	43	43	43
T	-4.387	-3.949	-1.103
Sig. of simple slope	0.000	0.000	0.276

* $p<0.05$; ** $p<0.01$

As shown in Table 5.48, the effect of SCI on ASR is negative and significant when PHI is high (PHI=+1 Std. Dev) and at mean level (PHI=mean value), but no longer significant when PHI is low (PHI=-1 Std. Dev). The variance of the simple slope for ASR on SCI at different levels of PHI indicates a stronger positive effect of SCI on the reduction of accident severity rate of building projects under higher project hazard level.

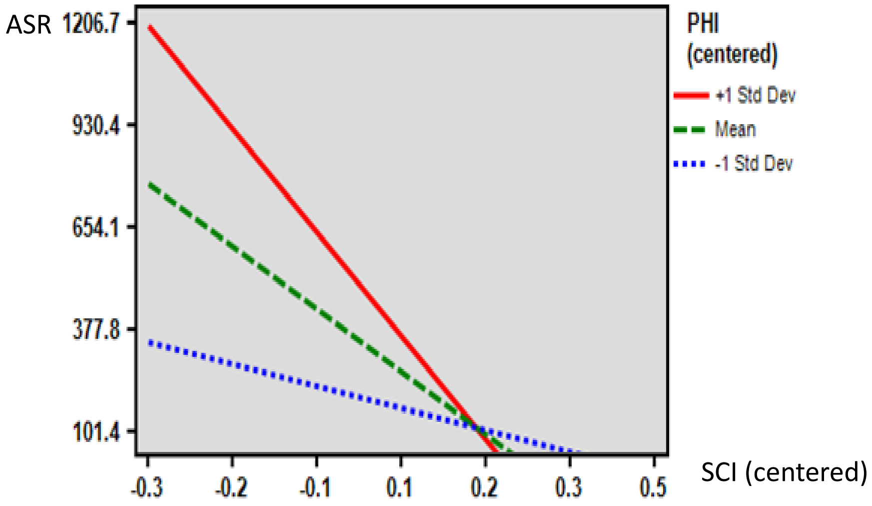


Figure 5.38: Simple Regression Lines for ASR on Centered SCI at Three Values of Centered PHI

5.3.5.2 Moderated effects (interaction effects) of safety culture level and project hazard level on AFR

To test the moderated effects (interaction effects) of SCI and PHI to AFR, the regression model postulates that AFR is a linear function of SCI, PHI, and the interaction of SCI and PHI (SCI * PHI) (Eq. 5.13).

$$AFR = \beta_0 + \beta_1 \cdot SCI + \beta_2 \cdot PHI + \beta_3 \cdot SCI \cdot PHI + \varepsilon \quad \text{……………………..(Eq. 5.13)}$$

Where the intercept β_0 and the slopes (β_1, β_2 , β_3) are unknown constants, ε is a random error component.

The results of moderated regression analysis were presented in Table 5.49 and Table 5.50. As shown in Table 5.50, the *t*-value for the coefficient of the product term is 1.54 with an associated probability of 0.131, thus it is possible that the regression coefficient has arisen by sampling error. In addition, the R^2 contribution of the interactive effect of SCI and PHI on AFR was found to be low (4%). Therefore, the effect of SCI on AFR is not moderated by the PHI.

*Table 5.49: Model Summary (Regress AFR on SCI, PHI and SCI *PHI)*

Model Summary	
R	0.516
R^2	0.267
Adjusted R^2	0.215
Standard Error of the Estimate	11.094
F	5.212
Sig.	0.004
R^2 Contribution of the Product Term	0.04

*Table 5.50: Model Coefficients (Regress AFR on SCI, PHI and SCI *PHI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	20.935	1.621	12.908	0.000
Centered SCI	-33.000	9.239	-3.572	0.001
Centered PHI	5.228	3.097	1.688	0.098
Product term	28.754	18.676	1.540	0.131

5.3.6 Relationship between accident frequency rate (AFR) and accident severity rate (ASR)

This study aims to develop a model for determining safety performance of building projects (see objective 2 in Section 1.4). However, it was found that the two indicators of safety performance (ASR and AFR) are correlated with different sets of variables (see Section 5.3.1). ASR is significantly ($p < 0.05$) correlated to SCI ($r = -0.46$) and PHI ($r = 0.363$). AFR is significantly ($p < 0.05$) correlated with TSIR ($r = -0.436$), BSIR ($r = -0.282$), VSIR ($r = -0.539$), and SCI ($r = -0.439$). This finding suggests that AFR and ASR may measure the different aspects of safety performance. It also suggests that the differences and relationship between AFR and ASR should be recognized in the model for determining safety performance of building projects.

This section examines the relationship between the two indicators of safety performance (AFR and ASR). Figure 5.14 (in Section 5.3.1) shows that ASR is significantly ($p < 0.05$) and positively correlated with AFR ($r = 0.512$) and PHI ($r = 0.363$), while no significant ($p > 0.05$) correlation was found between AFR and PHI ($r = 0.155$). Moderation analysis (see Section 4.4.3) was conducted to test if the relationship between ASR and AFR is moderated by PHI.

Before the regression analysis is carried out, the basic assumptions (refer to Section 4.4.2 for details) underlying regression analysis are checked. Examination of the scatterplots (Figure 5.14) does not reveal either apparent nonlinear relationships or a dramatically different type of dot cluster. The histograms of the variables (refer to Figures 5.6, 5.7 and 5.11) indicate that the variable PHI has an approximate normal distribution, whilst variables AFR and ASR exhibit positively skewed distribution. As regression analysis has been shown to be quite robust even when the normality assumptions are violated, then the original variables may be preferred for the comparability in the interpretation phase (Hair *et al.*, 1998). Thus, transformations are not deemed necessary.

The scatter plots were used to explore the patterns of the relationships between AFR and ASR. To explore whether the patterns are different under different project hazard conditions, three scattergrams are presented: (1) plotting the scatters using all cases (Figure 5.39); (2) plotting the scatters under higher project hazard level (i.e. when PHI >mean = 2.90) (see Figure 5.40); and (3) plotting the scatters under lower project hazard level (i.e. when PHI ≤ 2.90) (see Figure 5.41).

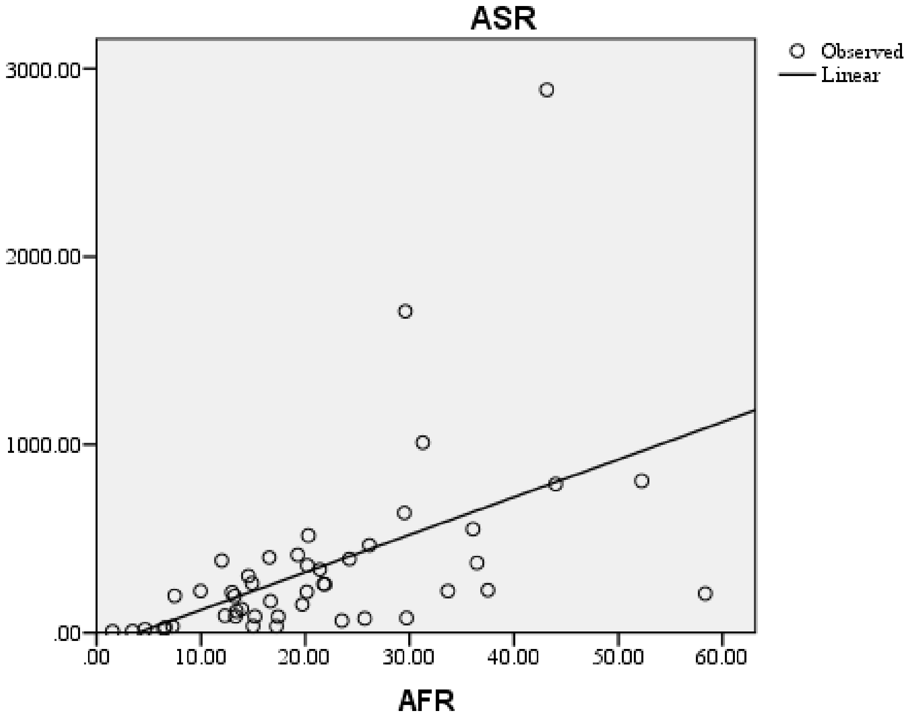


Figure 5.39: Plotting ASR on AFR (all Cases)

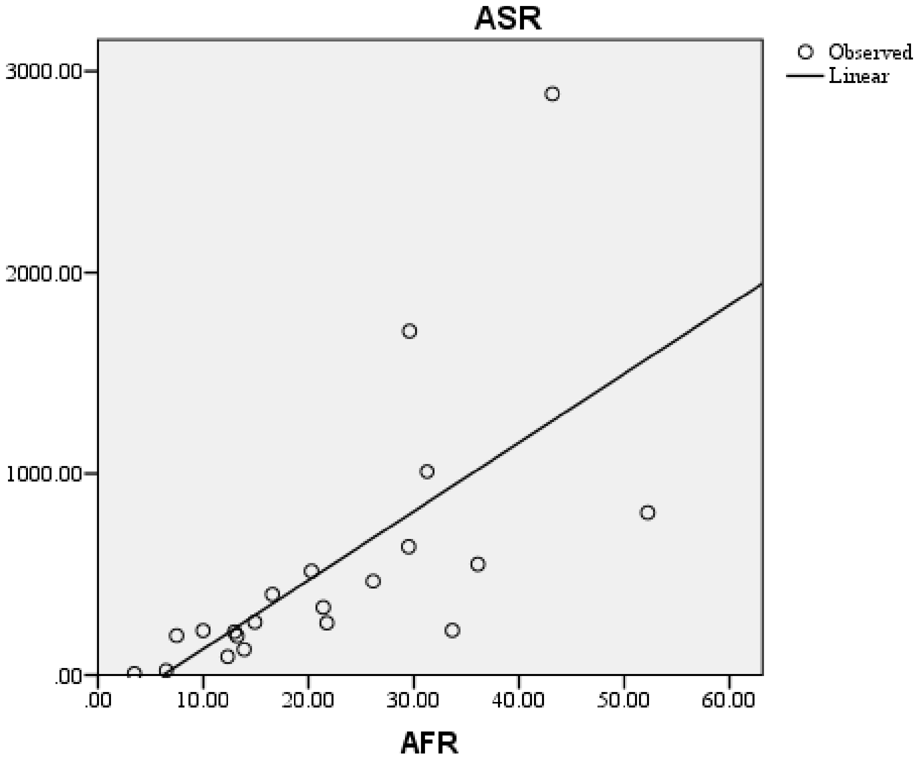


Figure 5.40: Plotting ASR on AFR (When PHI >2.90)

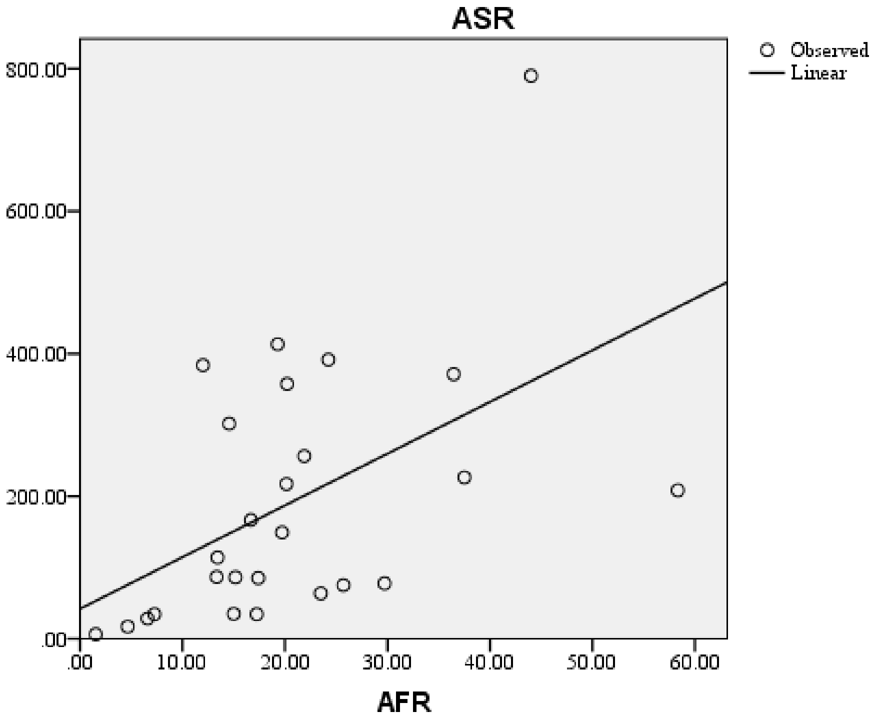


Figure 5.41: Plotting ASR on AFR (When PHI ≤2.90)

The regression model postulates that ASR is a linear function of AFR, PHI, and the interaction of AFR and PHI (AFR * PHI) (Eq. 5.14).

$$ASR = \beta_0 + \beta_1 \bullet AFR + \beta_2 \bullet PHI + \beta_3 \bullet AFR \bullet PHI + \varepsilon \text{……………….…..(Eq. 5.14)}$$

where the intercept β_0 and the slopes (β_1, β_2, β_3) are unknown constants, ε is a random error component. The results of regression analysis are presented in Table 5.51 and Table 5.52. It shows that the interaction term between AFR and PHI (AFR * PHI) has a significant effect on ASR ($p<0.05$). The R^2 contribution of the interactive effect on ASR is 4.4%.

*Table 5.51: Model Summary (Regress ASR on AFR, PHI and AFR *PHI)*

Model Summary	
R	0.624
R^2	0.389
Adjusted R^2	0.346
Standard Error of the Estimate	395.82
F	9.121
Sig.	0.000
R^2 Contribution of the Product Term	0.044

*Table 5.52: Model Coefficients (Regress ASR on AFR, PHI and AFI *PHI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	327.80	58.36	5.62	0.000
Centered AFR	17.68	4.72	3.74	0.001
Centered PHI	230.33	110.76	2.08	0.043
Product term	14.68	8.30	2.07	0.043

Three simple regression equations for ASR on centered AFR at three values of centered PHI (+1 Std. Dev., mean, and -1 Std. Dev.) were summarized in Table 5.53, and the lines were plotted in Figure 5.42.

Table 5.53: Summary of Simple Regression Equations for ASR on Centered AFR at Three Values of Centered PHI

	Simple regression line 1 (PHI $_{+1 \text{ Std. Dev.}}$)	Simple regression line 2 (PHI $_{\text{mean}}$)	Simple regression line 3 (PHI $_{-1 \text{ Std. Dev.}}$)
Moderator	PHI	PHI	PHI
Level of the Moderator	+1 Std. Dev.	Mean	-1 Std. Dev
Simple slope	25.62	17.68	9.74
Intercept	452.42	327.80	203.18
Std. Error of simple slope	6.30	4.73	6.73
Degree of Freedom	43	43	43
T	4.07	3.74	1.446
Sig. of simple slope	0.000	0.000	0.155

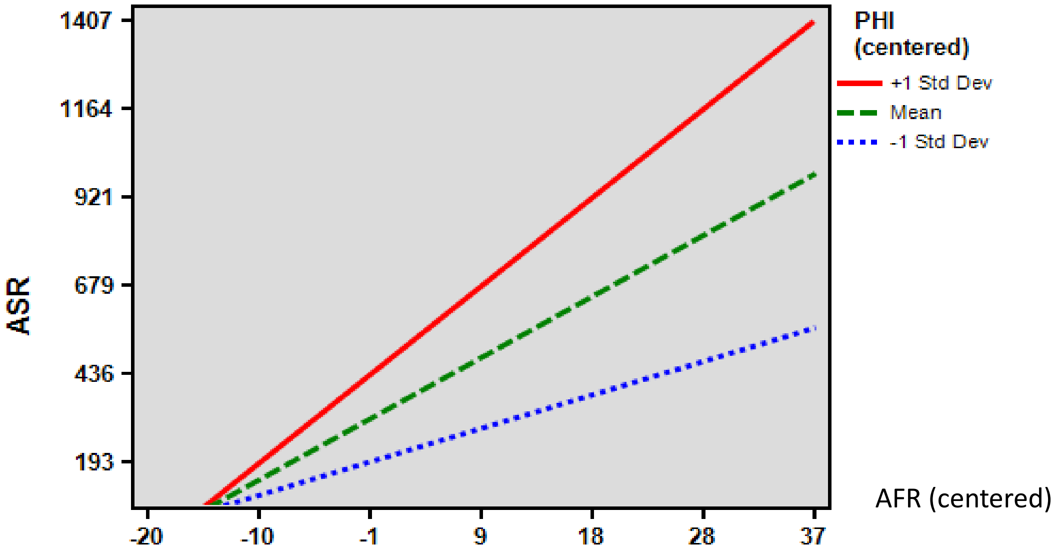


Figure 5.42: Simple Regression Lines for ASR on Centered AFR at Three Values of Centered PHI

As indicated in Table 5.53, the relationship between AFR on ASR is positive and significant when PHI is high (PHI = +1 Std. Dev) and at mean level (PHI =mean value), but no longer significant when PHI is low (PHI = -1 Std. Dev). The variance of the simple slope for ASR on AFR at different levels of PHI indicates a stronger positive relationship between AFR and ASR under higher project hazard conditions. This finding is discussed in Section 6.2.

5.4 Accident costs of building projects

This Section examines the costs of accidents to building contractors (objective 3 of this study). Section 5.4.1 estimates the accident costs of building projects. Section 5.4.2 addresses the magnitude of indirect accident costs and the factors influencing the magnitude of indirect accident costs. Section 5.4.3 investigates the factors influencing total accident costs of building projects and the factors influencing the relationship between accident frequency rate and total accident costs of building projects.

5.4.1 Estimation of accident costs of building projects

As presented in Section 4.3.1, the direct accident costs comprise the insured costs (DC_1), medical leave wages (not covered by insurance policy) (DC_2), medical expenses (not covered by insurance policy) (DC_3), and lump sum compensation for permanent incapacity or death (not covered by insurance policy) (DC_4). Based on the data collected from 47 building projects, the average direct accident costs for building projects in Singapore were estimated to be 0.165% of contract sum.

The indirect accident costs consist of the following 13 cost items:

- lost productivity due to the injured worker (IC_1);

- lost productivity due to crew of injured worker (IC_2);
- lost productivity due to other workers in vicinity of accident (IC_3);
- losses due to replacement of the injured worker (IC_4);
- lost productivity due to the investigation or inspections as a result of the injury (IC_5);
- cost of supervisory or staff effort (IC_6);
- damaged equipment or plant, property, material or finished work due to the accident (IC_7);
- cost of transporting injured worker (IC_8);
- consumption of first-aid materials (IC_9);
- additional work required as a result of the accident (e.g. cleaning, additional barriers and so on) (IC_{10});
- fines and legal expenses (IC_{11});
- losses due to Stop Work Orders (SWO) issued to the project (IC_{12}); and
- additional benefits to the injured worker beyond the Work Compensation Act (WCA) (IC_{13}).

The survey result shows that the average indirect accident costs of the 47 building projects were 0.086% of contract sum. The survey result further reveals that not all the above 13 cost items were encountered by each of the accidents. Figure 5.43 shows how often the 13 cost items were encountered in connection with the 168 MOM reportable accidents collected. It was found that there are large variations in the frequency in which these items were involved in the 168 accidents. As shown in Figure 5.43, the items with relatively lower incidence rate (less than 30% of total accidents) include: lost productivity due to other workers in vicinity of accident (IC_3); fines and legal expenses (IC_{11}); losses due to SWO issued to the project (IC_{12}); and additional benefits to the injured worker beyond WCA (IC_{13}). The items with relatively higher incidence rate (more than 70% of total accidents) include: lost productivity due to crew of the injured worker (IC_2); cost of supervisory or staff effort (IC_6); cost of transporting injured worker (IC_8); and consumption of first-aid materials (IC_9).

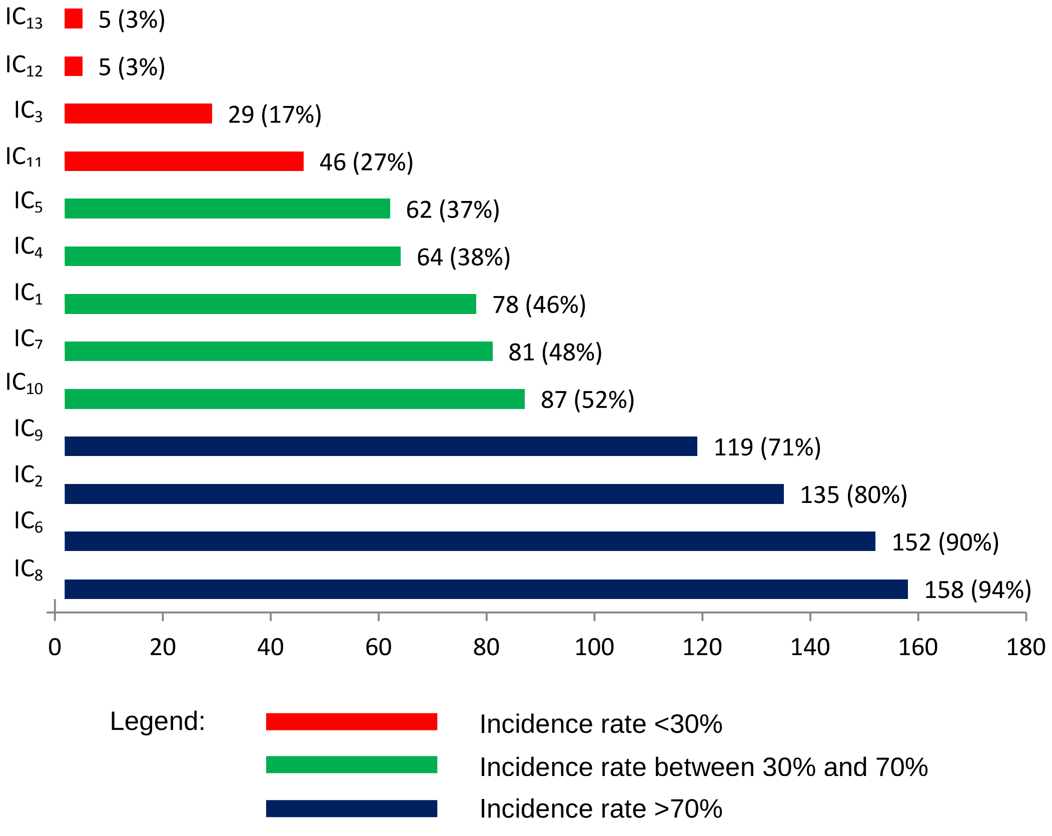


Figure 5.43: Occurrence of Indirect Accident Cost Items

Total accident costs (TAC) of building projects comprise the direct accident costs (DAC) and indirect accident costs (IAC). Among the 47 building projects examined, there is a large variation in TACR, which ranges from 0.12% to 0.83%. The average

TACR is 0.25% of total contract sum of a building project. This result is not much different from Tang *et al.'s* (1997) study, where the average accident loss ratio (equivalent to TACR in this study) was 0.31% of contract sum of a building project in Hong Kong. The major reason for the difference of the two research studies may lie in the methods used to collect data of accident costs. Compared with the components of accident costs used by Tang *et al.* (1997), this study classified the compensation to injured workers into two categories: the compensation covered by insurance policy; and the compensation not covered by insurance policy. The former was measured by the insurance premium paid by the contractors; whist the latter was measured by the amount of money directly paid to the injured workers by the employers. However, in Tang *et al.* (1997)'s study, the compensation to the injured person was assumed to be fully undertaken by the contractors. This may partly account for why the average accident costs ratio of building projects in Tang *et al.* (1997)'s study is slightly higher than that of this study. Moreover, the difference between the two figures (i.e., 0.25% and 0.31%) may also be explained by the differences in compensation required by legislation, wage level, and price level between Singapore and Hong Kong.

5.4.2 Magnitude of indirect accident costs

5.4.2.1 Estimation of indirect to direct accident costs ratio

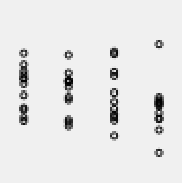
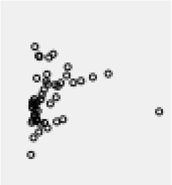
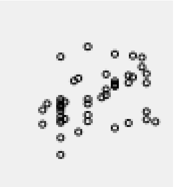
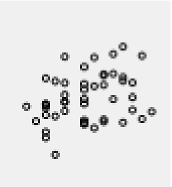
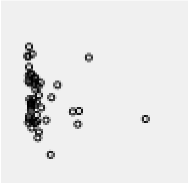
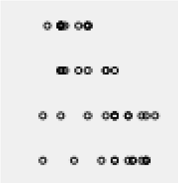
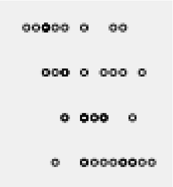
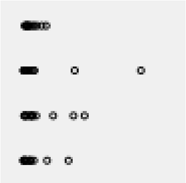
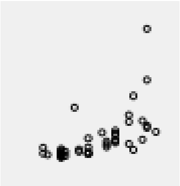
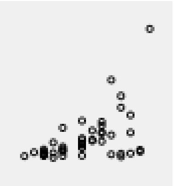
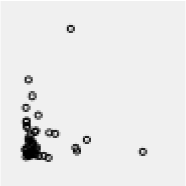
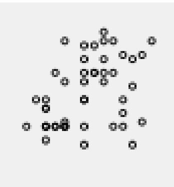
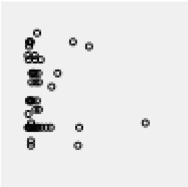
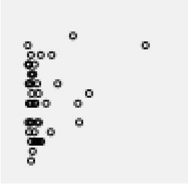
Based on the definition (see Section 2.4.2), direct costs of accidents tend to be those associated with the treatment of the injury and any unique compensation offered to workers as a consequence of being injured (Hinze, 1997). These costs are explicit and easily ascertained by employers. However, the indirect costs remain, for the most part, either hidden or attributed to other accounting ledgers (Brody *et al.*, 1990). To show the magnitude of indirect accident costs to employers, the ratio between indirect accidents costs and direct accidents costs building projects was examined.

In this study, the average indirect accident cost was estimated to be 0.086% of total contract sum of a building project, and the average direct accident cost was estimated to be 0.165% of contract sum. Thus, a ratio between the average indirect accident costs and average direct accident costs of building projects was obtained, in the order of 1: 1.92. This result shows that the indirect accident costs account for about 50% of the direct accident costs. For every dollar paid by employers for the treatment and compensation of the injured worker, there would be additional 0.5 dollar of “hidden” losses. It suggests that the “hidden” costs of accidents are substantial, and therefore the focus on the perceived or explicit costs of accidents fails to show the “true reality” of accident costs. This finding reinforces Brody *et al.*’s (1990) study, which found that the existence of the indirect accident costs would stimulate additional prevention expenditures. It is consistent with the findings of many studies (Head and Harcourt, 1997; Everett and Frank, 1996; Hinze, 1991; Leopold and Leonard, 1987; Heinrich, 1931) that the indirect accident costs are significant and should be paid much attention to.

5.4.2.2 Factors influencing the costs ratio

Bivariate correlation analysis was conducted to determine whether the ratio of indirect to direct accident costs is affected by project characteristics, such as company size (CS), project size (PS), project duration (PD), project hazard index (PHI) and percentage of work completed by sub-contractors (SUB). The results of correlation analysis presented in Figure 5.44 show that the indirect to direct accident costs ratio is significantly ($p < 0.05$) and positively correlated with the percentage of work completed by subcontractors ($r = 0.345$) and company size of contractors ($r = 0.292$).

Figure 5.44: Factors Influencing the Ratio of Indirect Costs to Direct Costs

	PHI	CS	PS	PD	SUB	IAC /DAC
PHI	1					
CS	0.282	1				
PS	0.225	0.593**	1			
PD	0.399**	0.621**	0.630**	1		
SUB	.314*	.561**	.517**	.397**	1	
IAC /DAC	.314	.292*	.027	.163	.345*	1

** p< 0.05 (2-tailed); ** p< 0.01 (2-tailed).*

- Percentage of work completed by subcontractors

The positive correlation between the indirect to direct accident costs ratio and the percentage of work completed by subcontractors (see Figure 5.44) suggests that the more the work is executed by subcontractors, the higher the indirect accident costs would be. The involvement of more employers in the construction site may explain some of the variations. The involvement of more subcontractors in the project tends to increase the levels of management. It seems that, in a construction site with more subcontractors, more people would be involved in the administration, communication, investigation and inspection processes when an accident occurs. Thus the costs incurred in these processes due to the occurrence of an accident tend to be relatively higher if more work is undertaken by subcontractors.

The influence of percentage of work undertaken by subcontractors on the magnitude of indirect accident costs could also be partly explained by the findings of Hinze (1991) that the cost ratios between indirect and direct cost vary with different types of contract such as lump sum contracts and cost reimbursable contracts. Hinze (1991) argued that a poorly managed cost reimbursable contract provides an inherent incentive for sub-contractors to increase costs. Moreover, where more subcontractors are employed, more costs would be incurred by those actions such as accident investigation, lessons communication, remedial measures implementation, etc.

- Company size

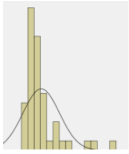
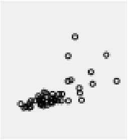
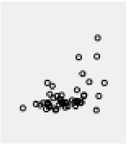
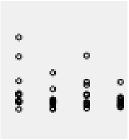
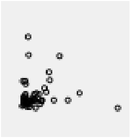
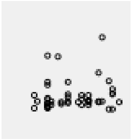
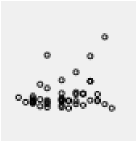
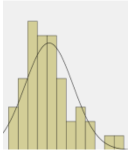
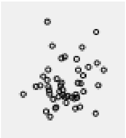
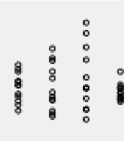
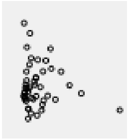
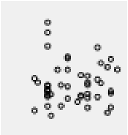
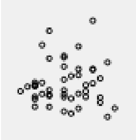
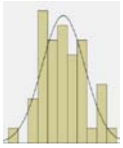
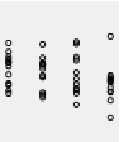
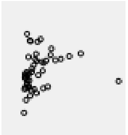
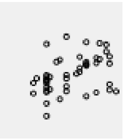
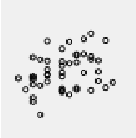
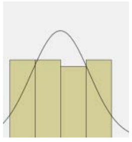
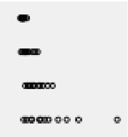
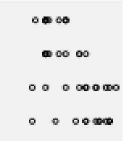
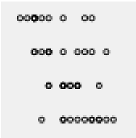
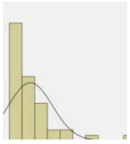
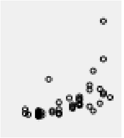
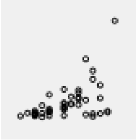
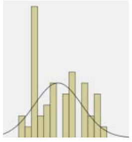
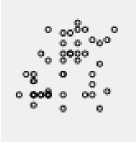
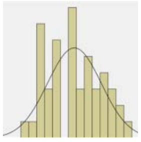
The positive correlation between the indirect to direct costs ratio and company size (see Figure 5.44) indicates that more indirect costs would be incurred by the accidents in larger contractors. This result supports Rikhardsson and Impgaard's (2004) finding that more accident costs would be incurred in larger companies than in smaller companies. Rikhardsson and Impgaard (2004) found that, when an accident occurs in larger companies, more formal activities are initiated than in smaller companies. More people tend to be involved; more internal administrative processes need to be complied with; and more organisational levels have to be informed.

As the projects of larger companies are generally larger than those of smaller companies, Hinze's (1991) study provides another possible reason for the positive relationship between company size and the costs ratio. Hinze (1991) found that larger projects generally employ greater numbers of workers resulting in work being performed in more crowded conditions, and thus an injury would be expected to have a broader indirect cost impact on a larger project.

5.4.3 Factors influencing total accident costs

Total accident costs of building projects are sum of direct accident costs and indirect accident costs. Bivariate correlation analysis was conducted to identify the factors influencing the total accident costs of building projects. The results presented in Figure 5.45 show that TACR is significantly ($p < 0.05$) and positively correlated to AFR ($r = 0.668$) and PHI ($r = 0.489$). This result suggests that more costs tend to be incurred with the increase of accident frequency rate and project hazard level.

Figure 5.45: Factors Influencing Total Accident Costs

	TACR	AFR	PHI	CS	PS	PD	SUB
TACR							
AFR	0.668**						
PHI	0.489**	0.155					
CS	0.223	0.027	0.282				
PS	0.031	-0.100	0.225	0.593**			
PD	0.098	-0.007	.399**	0.621**	0.630**		
SUB	0.247	0.024	0.314*	0.561**	0.517**	0.397**	

* *p*<0.05 (2-tailed); ** *p*<0.01 (2-tailed).

To explore whether the patterns of the relationships between AFR and TACR are different under different project hazard conditions, scatter plots were used. In this regard, three scattergrams are presented: (1) plotting the scatters using all cases (Figure 5.46); (2) plotting the scatters under higher project hazard level (i.e. when

PHI >mean = 2.90) (see Figure 5.47); and (3) plotting the scatters under lower project hazard level (i.e. when PHI ≤ 2.90) (see Figure 5.48).

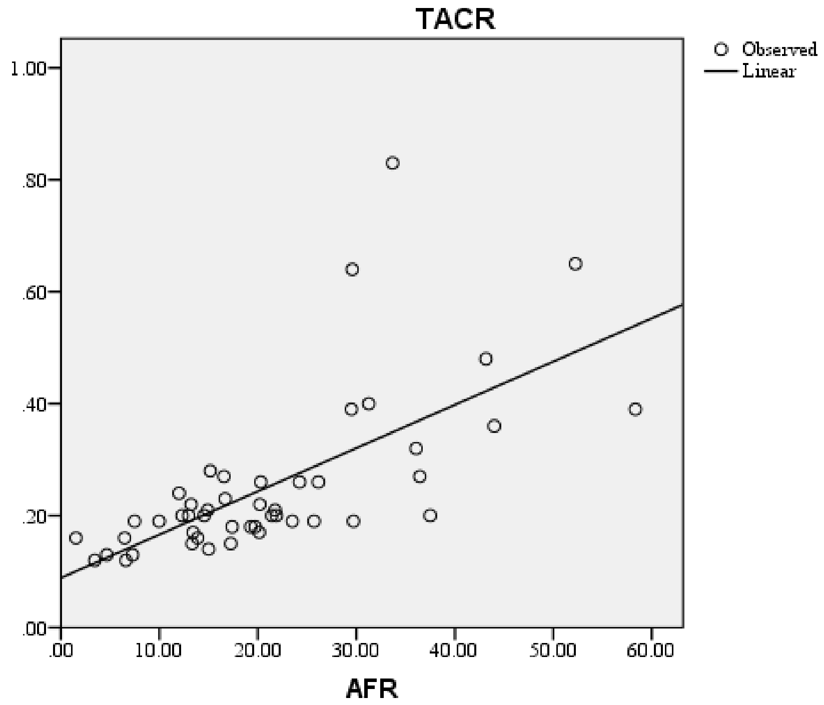


Figure 5.46: Plotting TACR on AFR (All Cases)

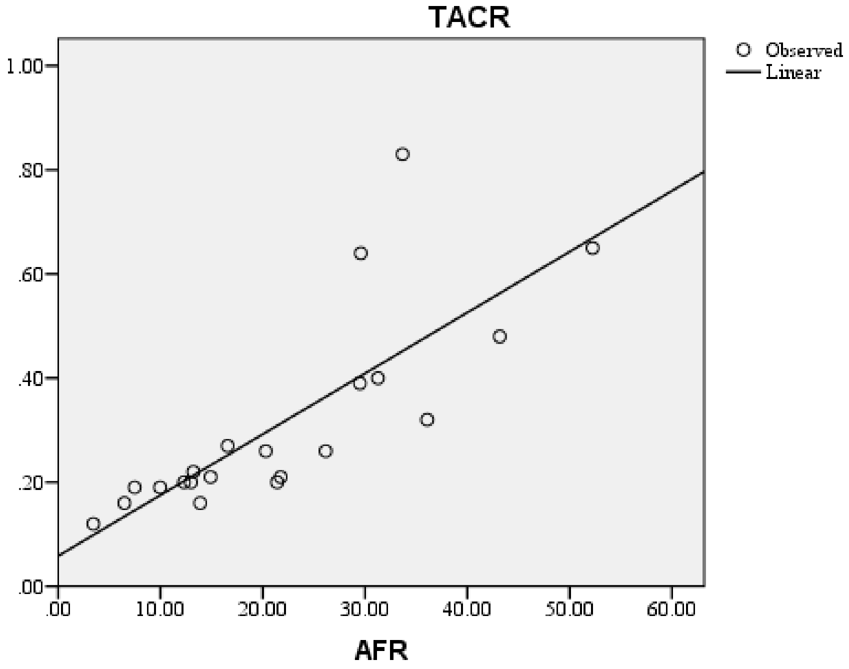


Figure 5.47: Plotting TACR on AFR (When PHI >2.90)

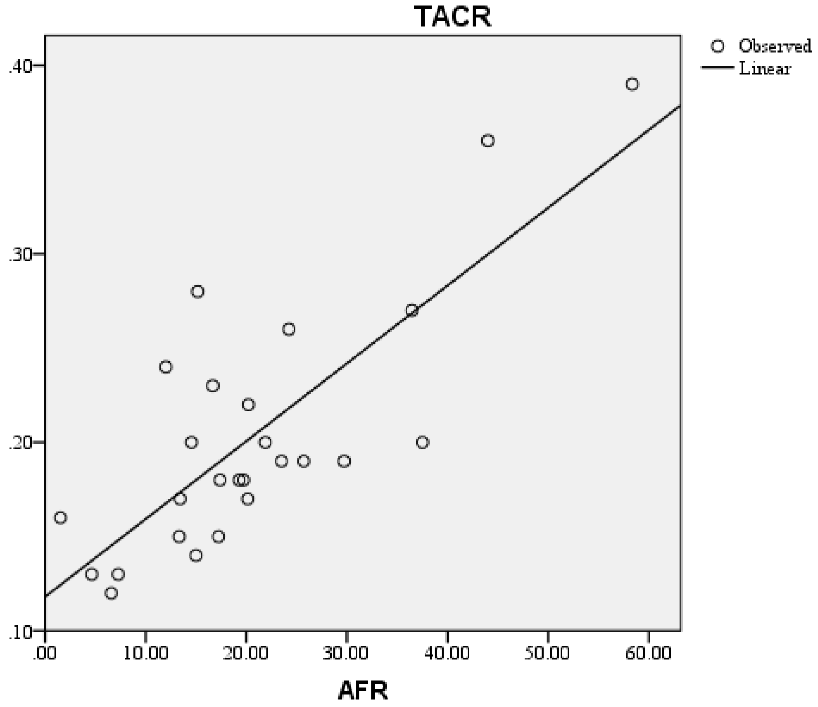


Figure 5.48: Plotting TACR on AFR (When PHI ≤2.90)

Moderated regression analysis (see Section 4.4.3) was applied to test if there are interactive effects of AFR and PHI on total accident cost. Before the regression analysis was carried out, the basic assumptions (refer to Section 4.4.2 for details) underlying regression analysis were checked. Examination of the scatterplots (Figure 5.45) does not reveal either apparent nonlinear relationships or a dramatically different type of dot cluster. The histograms of the variables (refer to Figures 5.7, 5.11 and 5.13) indicate that all the three variables (i.e., AFR, PHI and TACR) exhibit positively skewed distribution. As regression analysis has been shown to be quite robust even when the normality assumptions are violated, then the original variables may be preferred for the comparability in the interpretation phase (Hair *et al.*, 1998). Thus, transformations are not deemed necessary. The results of regression analysis are presented in Tables 5.54 and 5.55. Table 5.55 shows that the interaction term between

AFR and PHI (AFR * PHI) has a significant effect on TACR (p<0.05). The R^2 contribution of the interactive effect on TACR is 8.7% (see Table 6.3).

*Table 5.54: Model Summary (regress TACR on AFR, PHI and AFR*PHI)*

Model Summary	
R	0.828
R^2	0.685
Adjusted R^2	0.663
Standard Error of the Estimate	0.084
F	31.159
Sig.	0.000
R^2 Contribution of the Product Term	0.087

*Table 5.55: Model Coefficients (regress TACR on AFR, PHI and AFR*PHI)*

Model	*B*	*Std. Error*	*t*	*Sig.*
Constant	0.245	0.012	19.79	0.000
Centered AFR	0.006	0.001	6.75	0.000
Centered PHI	0.092	0.023	3.92	0.000
Product term	0.006	0.002	3.44	0.001

Three simple regression equations for TACR on centered AFR at three values of centered PHI (+1 Std. Dev., mean, and -1 Std. Dev.) are summarized in Table 5.56, and the lines are plotted in Figure 5.49.

Table 5.56: Summary of Simple Regression Equations for TACR on Centered AFR

	Simple regression line 1 ($\text{PHI}_{+1\text{ Std. Dev.}}$)	Simple regression line 2 (PHI_{mean})	Simple regression line 3 ($\text{PHI}_{-1\text{ Std. Dev.}}$)
Moderator	PHI	PHI	PHI
Level of the Moderator	+1 Std. Dev.	Mean	-1 Std. Dev
Simple slope	0.010**	0.007**	0.004*
Intercept	0.296	0.246	0.196
Std. Error of simple slope	0.001	0.001	0.001
Degree of Freedom	43	43	43
t	7.518	6.756	2.450
Sig. of simple slope	0.000	0.000	0.018

** p<0.05; ** p<0.01*

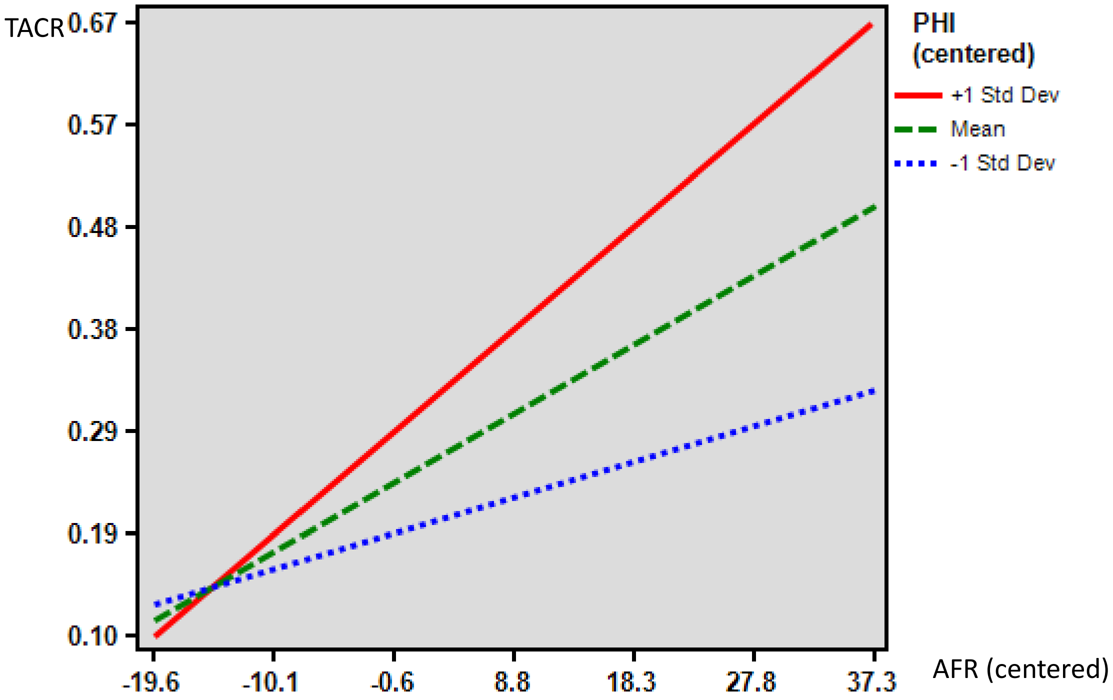


Figure 5.49: Simple Regression Lines for TACR on Centered AFR

The variations of the simple slopes show that there is a stronger positive effect of AFR on TACR under higher project hazard level. The relationship between the number of accidents and the total costs of accidents of a building project is dependent on the project hazard level. One possible reason is that the higher level of project hazard (e.g., higher heights of building and more work in confined spaces) tends to be associated with greater chance of severe accidents, which would incur more medical expenses and compensation for the injured workers. Moreover, longer period of absence of injured workers due to the more severe injuries may result in higher indirect costs of accidents. For example, it appears unnecessary for contractors to hire another worker to replace the worker with less severe injuries (e.g., less than 7 days of medical care) because the injured worker is expected to return to work in a short period (i.e., less than 7 days). Nevertheless, longer period of absence of injured workers (e.g., more than 30 days of absence), especially those who are responsible for a key function in the production process or have key responsibilities, would impact the productivity of the work group and the schedule of the project, which would force the contractors to employ another worker to replace the injured worker. In such cases, additional costs tend to be incurred by the recruitment, selection, training and certification of new workers (Hinze, 1997).

5.5 Optimization of safety investments

This Section addresses objective 4 (i.e., to study the optimization of safety investments for building projects) of this study. Section 5.5.1and Section 5.5.2 estimate the equations for predicting voluntary safety investments ratio (VSIR curve) and total accident costs ratio (TACR curve), respectively. Then, the model for predicting total controllable safety costs ratio (TCCR curve) is constructed through the combination of VSIR curve and TACR curve (see Section 5.5.3). The safety investments optimization model is developed with the objective of minimizing total controllable safety costs ratio for building projects (see Section 5.5.3). The curves of voluntary safety investments (VSIR curve), total accident costs (TACR curve), and total controllable safety costs (TCCR curve) are plotted under different project conditions. The financially optimum level of voluntary safety investments is quantified with three levels of safety culture and three levels of project hazard (see Section 5.5.3).

5.5.1 Equation for predicting voluntary safety investments

5.5.1.1 Development of regression model

Based on the analysis in Section 5.3.4, voluntary safety investments ratio was negatively related to accident frequency rate and the relationship between voluntary safety investments ratio and accident frequency rate was affected by the level of safety culture. Therefore, voluntary safety investments ratio could be predicted using accident frequency rate and safety culture index. Multiple regression modeling (see Section 4.4.2) was used to estimate the equation for predicting voluntary safety investments ratio. To determine (or approximate) the functional form for the relationship between VSIR and AFR, a limited amount of experimentation was conducted using the approach described in Section 4.4.2. The linear, log-log (for double log), and exponential versions of the model were estimated and then the "best" one was chosen among the alternative model specifications.

Following the method of regression modeling in Section 4.4.2, the linear, log-log (for double log), and exponential functional forms for predicting VSIR are given below.

- Basic linear functional form

$$VSIR = \beta_0 + \beta_1 \bullet SCI + \beta_2 \bullet AFR + \beta_3 \bullet SCI \bullet AFR + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.15)}$$

- Log-log functional form

$$\ln (VSIR) = \beta_0 + \beta_1 \bullet SCI + \beta_2 \bullet \ln (AFR) + \beta_3 \bullet SCI \bullet \ln (AFR) + \varepsilon \ldots\ldots \textit{(Eq. 5.16)}$$

- Exponential function form

$ln\ (VSIR) = \beta_0 + \beta_1 \bullet SCI + \beta_2 \bullet AFR + \beta_3 \bullet SCI \bullet AFR + \varepsilon$ ………………(Eq. 5.17)

To overcome the threat of multicollinearity in interactive models, the variables were centered (prior to forming the multiplicative term) by subtracting the mean variable value from each score of the variables (see Section 4.4.2). Table 5.57 reports estimates for these three types of functional forms. Model 1 is the log-log model; model 2 is the exponential model; and model 3 is the basic linear model.

Table 5.57: Comparison of Three Regression Models for Predicting VSIR

Variable	(Model 1) log-log Ln VSIR		(Model 2) exponential Ln VSIR		(Model 3) basic linear VSIR	
	Coef.	*t*	Coef.	*t*	Coef.	*T*
$(\text{Ln (AFR)})_{\text{centered}}$	-0.154**	-3.409	------	------	------	------
$\text{AFR}_{\text{centered}}$	------	------	-0.010**	-4.136	-0.005**	-3.952
$\text{SCI}_{\text{centered}}$	0.187	1.089	0.257	1.551	0.134	1.635
$(\text{SCI})_{\text{centered}}\ (\text{Ln AFR})_{\text{centered}}$	-0.455*	-2.268	------	------	------	------
$(\text{SCI})_{\text{centered}}\ (\text{AFR})_{\text{centered}}$	------	------	-0.031**	-3.273	-0.016**	-3.361
CONSTANT	-0.825**	-28.913	-0.828**	-30.209	0.448**	32.976
F	11.657		12.04		11.719	
Sig.	0.000		0.000		0.000	
Adjusted R^2	0.410		0.418		0.411	

*$p<0.05$; **$p<0.01$

The criteria for choosing the best functional form were presented in Section 4.4.2. As shown in Table 5.57, all three of the models produce similar results regarding the signs and statistical significance of the variables, the error distributions, and the adjusted R^2 in different models. However, Brody *et al.* (1990) found that at extremely low levels of risk the preventive costs curve is asymptotic to the vertical axis (see Figure 2.5). This indicates that the elimination of all risks is unlikely even with huge prevention expenditures. It seems that the curve derived by the log-log functional form is the best one to meet this condition. Consequently, the log-log model was selected as the most appropriate model for predicting VSIR of building projects.

As shown in Table 5.57, as the effect of SCI on VSIR was not significant ($r = 0.187$, $p > 0.05$), it was dropped from the regression model to increase the power of prediction. The parameters of the log-log model were re-estimated and reported in Table 5.58.

Table 5.58: Adjusted Log-Log Model for Predicting VSIR

Parameter	
R	0.659
R^2	0.434
Adjusted R^2	0.408
Standard error of the estimate	0.179
Durbin-Watson	2.113
F	16.852
Sig.	0.000
Constant	-0.823**
$(\text{Ln AFR})_c$	-0.177**
$(\text{SCI})_c \bullet (\text{Ln AFR})_c$	-0.405*

**p<0.05; **p<0.01*

Thus, the equation for predicting VSIR is written in Eq. 5.18.

$$Ln\ VSIR = -0.823 - 0.177 \bullet (Ln\ AFR)_c - 0.405 \bullet (SCI)_c \bullet (Ln\ AFR)_c \ldots\ldots\ldots \text{(Eq. 5.18)}$$

where $(\text{Ln AFR})_c$ and $(\text{SCI})_c$ are the centered variables and derived from Eq. 5.19 and Eq. 5.20.

$$(\text{Ln AFR})_c = \text{Ln AFR} - (\text{Ln AFR})_{mean} = \text{Ln AFR} - 2.85 \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.19)}$$

$(SCI)_c = SCI - (SCI)_{mean} = SCI – 3.58$………………………….……...…. (Eq. 5.20)

To enhance the validity of the estimated equation, the following assumptions (refer to Section 4.4.2 for details) underlying multiple regression analysis were checked:

The first assumption, linearity, was assessed through an analysis of residuals and partial regression plots. Figure 5.50 shows the analysis of Studentized Residuals. It does not exhibit any nonlinear pattern to the residuals, thus ensuring that the overall equation is linear. Figure 5.51 presents the partial regression plots for each independent variable in this equation (Eq. 5.18). As can be seen in Figure 5.51, for both independent variables, no nonlinear pattern is shown, thus meeting the assumption of linearity for each independent variable.

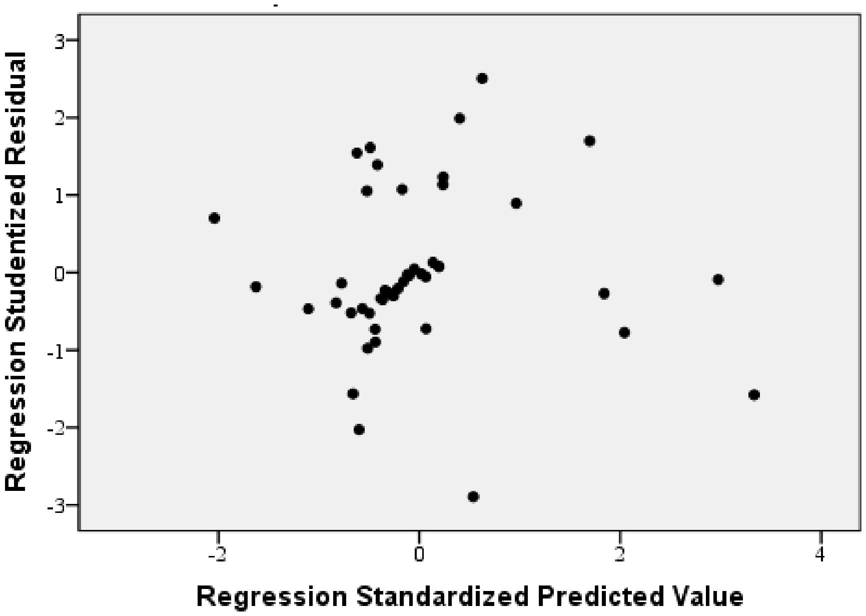


Figure 5.50: Analysis of Studentized Residuals

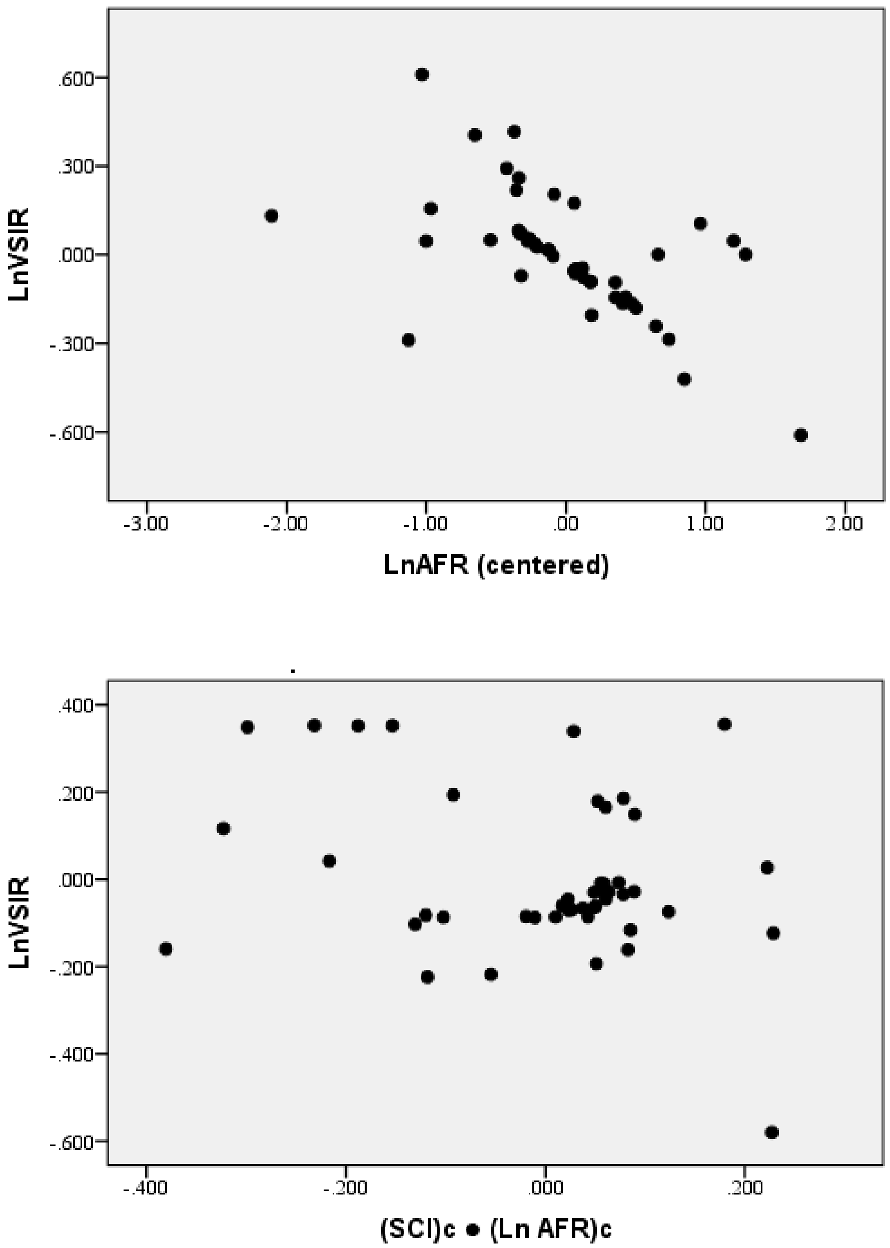


Figure 5.51: Partial Regression Plots

The next assumption deals with the constancy of the residuals across values of the independent variables, which can be tested through examination of the residuals plots. Figure 5.50 shows no pattern of increasing or decreasing residuals. This indicates homoscedasticity in the multivariate case.

The third assumption deals with the effect of carryover from one observation to another, thus making the residual not independent. Again, the analysis of residuals was used to check the independence of residuals. From Figure 5.50, no pattern was identified among predicted value and the residual. Moreover, Durbin-Watson test was also conducted. The Durbin-Watson test value is 2.113 (see Table 5.54) in this regression model. For N = 47, number of independent variables is 2, and *p* value = 0.05, the critical values for the Durbin-Watson Test are: D_{lower} = 1.44; and D_{upper} = 1.62. The Durbin-Watson test value (2.113) is greater than D_{upper} (1.62) but less than (4- D_{upper}) (2.38), thus indicating no serial dependency among the residuals in this sample.

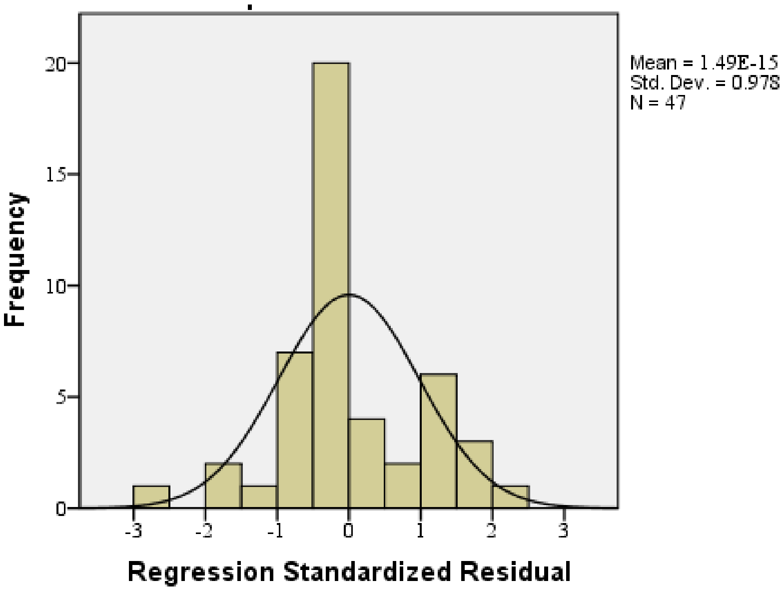


Figure 5.52: Histogram of Residuals

The final assumption is normality of the error term. Figure 5.52 presents the histogram of residuals. This figure shows that the mean of residuals is 0.000 and the shape is close to normal distribution. Thus, the regression variate was found to meet the assumption of normality.

Eq. 5.18, Eq. 5.19, and Eq. 5.20 were combined by substituting (Ln AFR – 2.85) for $(\text{Ln AFR})_c$ and (SCI – 3.58) for $(\text{SCI})_c$, then

$$Ln\ VSIR = (-4.451+1.154 \bullet SCI) + (1.273 - 0.405 \bullet SCI) \bullet Ln\ AFR$$

$$VSIR = e^{(-4.451+1.154 \bullet SCI)} \bullet AFR^{(1.273 - 0.405 \bullet SCI)} \text{………….………………. (Eq. 5.21)}$$

Eq. 5.21 shows that the VSIR curve varies with different levels of safety culture of the project. As shown in Figure 5.53, a typical VSIR curve is plotted at the mean value of SCI.

Eq. 5.21 indicates a general negative tendency of the relationship between voluntary safety investments and AFR of building projects. It further reveals the curvilinear nature of the relationship between safety investments and safety performance. This result is consistent with the finding of Tang *et al.* (1997), who also found a curvilinear relationship between safety investments and safety performance. It also reinforces the studies of Lingard and Rowlinson (2005), Hinze (2000), Brody *et al.* (1990), HSE (1993b), and Laufer (1987a, b), where they postulated a negative and curvilinear tendency for the relationship between safety investments and OSH risk exposure.

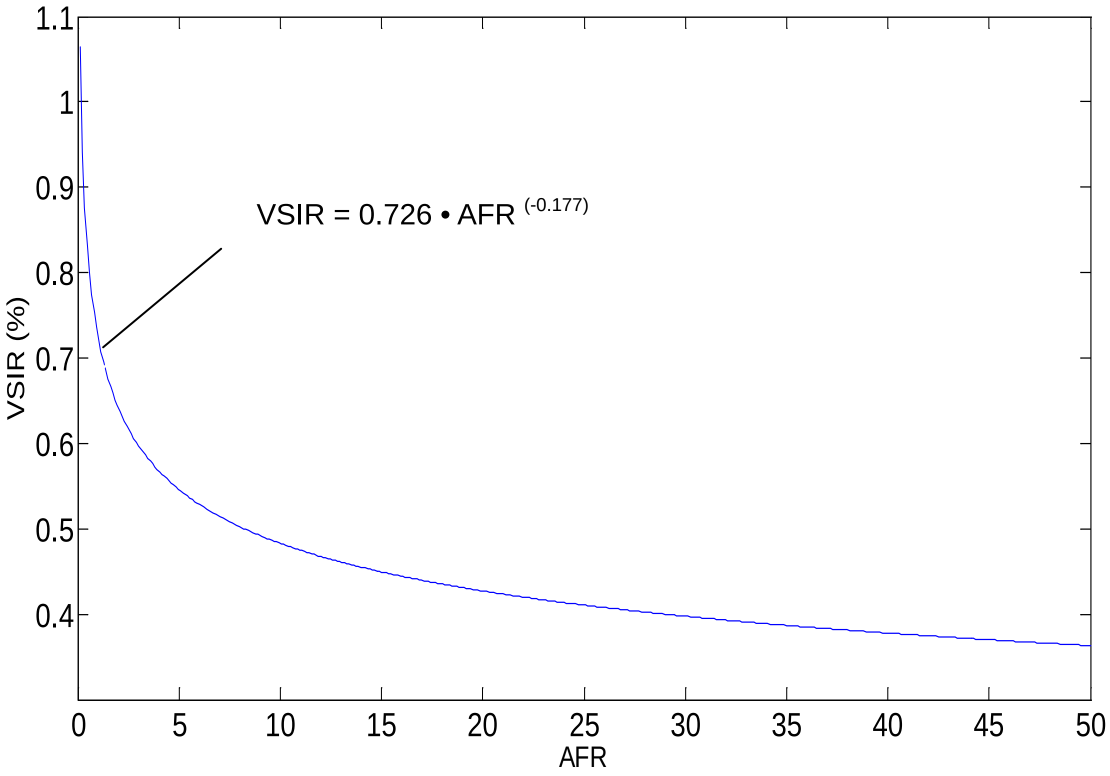


Figure 5.53: VSIR Curve under Mean Level of Safety Culture

5.5.1.2 Validation of regression model

In the previous section, the regression model (see Eq. 5.21) was developed to predict VSIR of building projects using AFR and SCI. Proper validation of the regression model was made to investigate its prediction performance. The model (Eq. 5.21) was next validated using the procedures described in Section 4.4.5.

The computation of *PRESS* statistic (see Section 4.4.5) for the prediction model of

Table 5.59: Validation of the Model for Predicting VSIR

	(1)	(2)	(3)	(4)
		Least-squares Fit		
Observation, *i*	Observed, y_i	Predicted, $\hat{y}_i$	Prediction Error, $e_i = y_i - \hat{y}_i$	Diagonal elements of the hat matrix, $h_{ii} = x'_i (X' X)^{-1} x_i$
1	-0.916	-0.854	-0.062	0.024
2	-0.994	-0.902	-0.092	0.034
3	-0.799	-0.806	0.007	0.031
4	-1.204	-0.891	-0.313	0.255
5	-0.755	-0.768	0.013	0.028
6	-1.05	-0.969	-0.081	0.049
7	-0.562	-0.516	-0.046	0.116
8	-1.079	-1.047	-0.032	0.108
9	-0.844	-0.823	-0.021	0.026
10	-0.994	-0.925	-0.069	0.036
11	-0.616	-0.485	-0.131	0.112
12	-0.545	-0.762	0.217	0.033
13	-0.994	-0.866	-0.128	0.046
14	-0.248	-0.538	0.290	0.090
15	-0.821	-0.814	-0.007	0.025
16	-0.774	-0.701	-0.073	0.089
17	-1.022	-0.865	-0.157	0.056
18	-0.635	-0.862	0.227	0.161
19	-0.892	-0.840	-0.052	0.024
20	-0.635	-0.893	0.258	0.121
21	-0.598	-0.874	0.276	0.087
22	-1.204	-0.715	-0.489	0.114
23	-0.528	-0.287	-0.241	0.279
24	-0.916	-0.788	-0.128	0.031
25	-0.562	-0.761	0.199	0.028
26	-0.635	-0.825	0.190	0.025
27	-0.693	-0.878	0.185	0.033
28	-0.494	-0.650	0.156	0.044
29	-1.171	-0.901	-0.270	0.061
30	-0.942	-0.917	-0.025	0.044
31	-0.916	-0.858	-0.058	0.025
32	-0.755	-0.778	0.023	0.030
33	-0.821	-0.816	-0.005	0.026
34	-0.799	-0.788	-0.011	0.025
35	-0.755	-0.768	0.013	0.028
36	-0.968	-0.874	-0.094	0.029
37	-0.892	-0.851	-0.041	0.025
38	-0.799	-0.796	-0.003	0.030

	(1)	(2)	(3)	(4)
		Least-squares Fit		
Observation, *i*	Observed, y_i	Predicted, $\hat{y}_i$	Prediction Error, $e_i = y_i - \hat{y}_i$	Diagonal elements of the hat matrix, $h_{ii} = x'_i (X' X)^{-1} x_i$
39	-0.386	-0.735	0.349	0.028
40	-0.892	-0.838	-0.054	0.023
41	-1.05	-0.878	-0.172	0.028
42	-0.968	-0.886	-0.082	0.029
43	-0.357	-0.342	-0.015	0.255
44	-0.892	-0.847	-0.045	0.025
45	-0.868	-0.830	-0.038	0.022
46	-0.994	-1.111	0.117	0.132
47	-0.799	-0.796	-0.003	0.027

VSIR (Eq. 5.21) is presented in Table 5.59. Column 1 of Table 5.59 shows the observed values of *y* (Ln VSIR), while column 2 shows the predicted values using the least-squares model developed from all the 47 data points (Eq. 5.21). Columns 3 and 4 present the computations of prediction error (e_i) and diagonal elements of the hat matrix (h_{ii}), which are used to calculate the PRESS statistic. Then

$$PRESS = \sum_{i=1}^{47}\left(\frac{e_i}{1-h_{ii}}\right)^2 = 1.156$$

$$R^2_{prediction} = 1 - \frac{PRESS}{SS_T} = 1 - \frac{1.556}{2.493} = 0.38$$

Therefore, as compared to the 40.8% of the variability in the original data explained by the least-squares fit, this model (Eq. 5.21) could be expected to explain about 38% of the variability in predicting new observations. This result indicates that the least-squares model predicts new observations almost as well as it fits the original data, as the "loss" in R^2 for prediction is slight (i.e., 2.8%, being 40.8% minus 38%). According to Montgomery *et al.* (2007), the small loss in R^2 provides reasonably strong evidence that the least-squares model will be a satisfactory predictor. Thus, the predictive capability of the model (Eq. 5.21) seems satisfactory.

5.5.2 Equation for predicting total accident costs

5.5.2.1 Development of regression model

Based on the analysis in Section 5.4, total accident costs ratio (TACR) is positively related to accident frequency rate (AFR) and the relationship between TACR and AFR is moderated by the project hazard index (PHI). Therefore, TACR could be predicted using AFR and PHI. Following the approach that were presented in Section 4.4.2, linear, log-log, and exponential versions of the model were developed and then to choose the best one as the model specification for predicting the total accident costs ratio of building projects. The linear, log-log (for double log), and exponential functional forms for predicting TACR are given below.

- Basic linear functional form

$$TACR = \beta_0 + \beta_1 \bullet PHI + \beta_2 \bullet AFR + \beta_3 \bullet PHI \bullet AFR + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.22)}$$

- Log-log functional form

$$ln\ (TACR) = \beta_0 + \beta_1 \bullet PHI + \beta_2 \bullet ln\ (AFR) + \beta_3 \bullet PHI \bullet ln\ (AFR) + \varepsilon \ldots\ldots \text{(Eq. 5.23)}$$

- Exponential function form

$ln\ (TACR) = \beta_0 + \beta_1 \bullet PHI + \beta_2 \bullet AFR + \beta_3 \bullet PHI \bullet AFR + \varepsilon$ ……………(Eq. 5.24)

To overcome the threat of multicollinearity in interactive models, the variables were centered (prior to forming the multiplicative term) by subtracting the mean variable value from each score of the variables (see Section 4.4.2). Table 5.60 presents estimates for these three types of functional forms. Model 1 is the log-log model; model 2 is the exponential model; and model 3 is the basic linear model.

Table 5.60: Comparison of Three Regression Models for Predicting TACR

Variable	(Model 1) Log-log Ln TACR		(Model 2) Exponential Ln TACR		(Model 3) Basic linear TACR	
	Coef.	*t*	Coef.	*t*	Coef.	*T*
(Ln AFR)$_{\text{centered}}$	0.390**	7.546	------	------	------	------
AFR $_{\text{centered}}$	------	------	0.024**	8.647	0.007**	6.756
PHI $_{\text{centered}}$	0.302**	4.425	0.283**	4.440	0.092**	3.921
(PHI) $_{\text{centered}}$ (Ln AFR) $_{\text{centered}}$	0.303**	3.317	------	------	------	------
(PHI) $_{\text{centered}}$ (AFR) $_{\text{centered}}$	------	------	0.013**	2.660	0.006**	3.438
CONSTANT	-1.503**	-41.528	-1.502**	-44.678	0.246**	19.793
F	33.997		42.099		31.159	
Sig.	0.000		0.000		0.000	
Adjusted R^2	0.682		0.729		0.663	
Durbin-Watson	2.167		2.070		2.083	

$^*p<0.05$; $^{**}p<0.01$

The criteria stated in Section 4.4.2 were applied to choose the best functional form for predicting TACR. As shown in Table 5.60, all the three models produce statistically significant coefficients with the same signs. Thus, each of the models satisfies the first criterion. Then, the error distributions of these models were compared (see Figures

5.54, 5.55 and 5.56). The comparison of the normal P-P plot of regression standardized residual of the three models shows that the error distributions of double log model (model 1) and exponential model (model 2) are closer to normal distribution than that of basic linear model (model 3). Thus, the double log model (model 1) and exponential model (model 2) are more appropriate than basic linear model in this case. Moreover, the adjusted R^2 s are comparable as the dependent variables of double log model (model 1) and exponential model (model 2) are consistent with one another (i.e., *Ln TACR*). Table 5.60 shows that the exponential model (model 2) has higher adjusted R^2 (0.729) compared with the double log model (model 1) (0.682). Therefore, the exponential functional form (model 2) was chosen as the best model for predicting TACR of building projects, and the formula is given in Eq. 5.25.

$$Ln\ TACR = -1.502 + 0.024 \bullet (AFR)_c + 0.283 \bullet (PHI)_c + 0.013 \bullet (PHI)_c \bullet (AFR)_c \quad \text{(Eq. 5.25)}$$

where $(AFR)_c$ and $(PHI)_c$ are the centered variables and derived from Eq. 5.26 and Eq. 5.27, respectively.

$$(AFR)_c = AFR - (AFR)_{mean} = AFR - 21.1 \quad \text{(Eq. 5.26)}$$

$$(PHI)_c = PHI - (PHI)_{mean} = PHI - 2.90 \quad \text{(Eq. 5.27)}$$

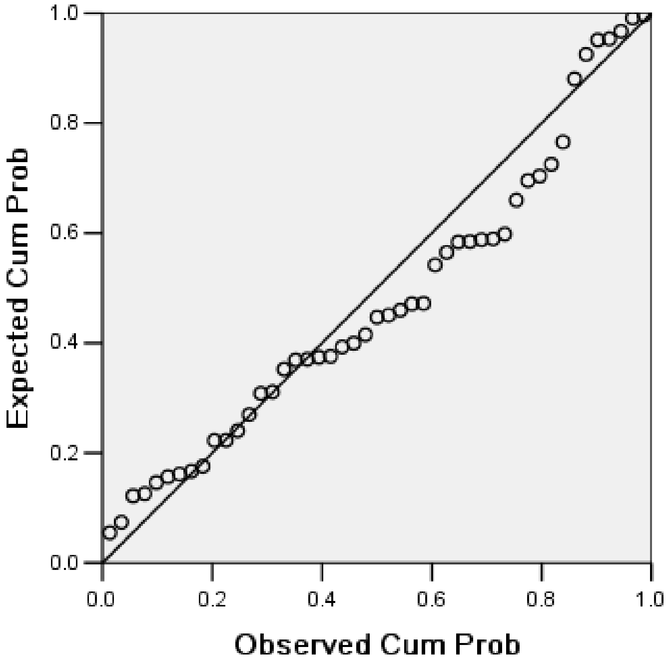


Figure 5.54: Normal P-P Plot of Regression Standardized Residual of Double Log Model

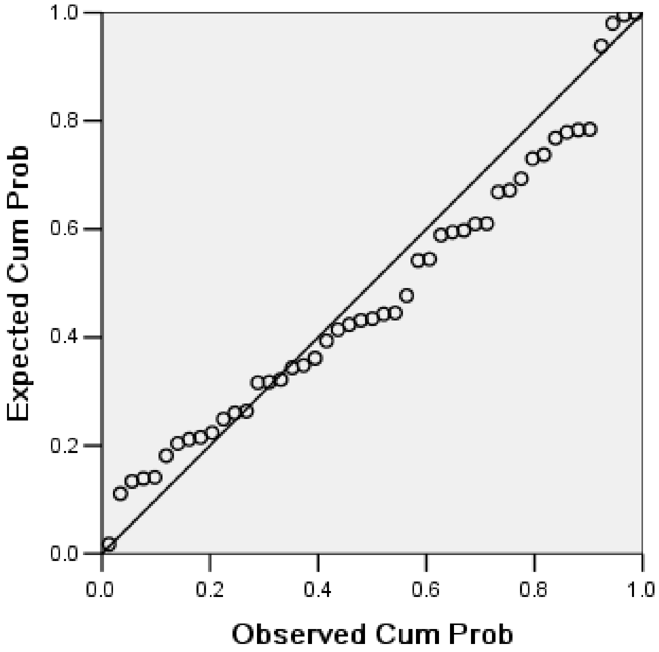


Figure 5.55: Normal P-P Plot of Regression Standardized Residual of Exponential Model

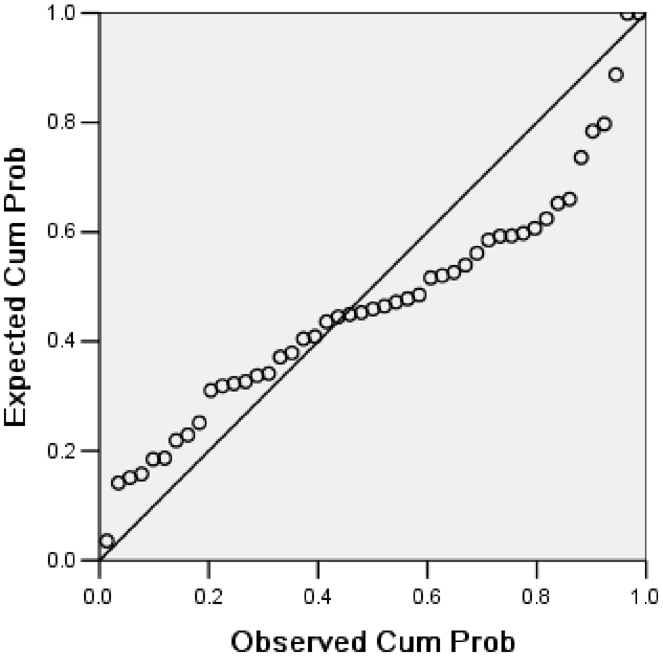


Figure 5.56: Normal P-P Plot of Regression Standardized Residual of Basic Linear Model

To evaluate the validity of the estimated equation (Eq. 5.27), the following assumptions (refer to Section 4.4.2 for details) underlying multiple regression analysis were checked:

The assumption of linearity was assessed through an analysis of residuals and partial regression plots. The Plot of Studentized Residuals (see Figure 5.57) does not exhibit any nonlinear pattern to the residuals, thus ensuring that the overall equation is linear. Figure 5.58 presents the partial regression plots for each independent variable in this equation (Eq. 5.27). As can be seen in Figure 5.58, for both independent variables, no nonlinear pattern is shown, thus meeting the assumption of linearity for each independent variable.

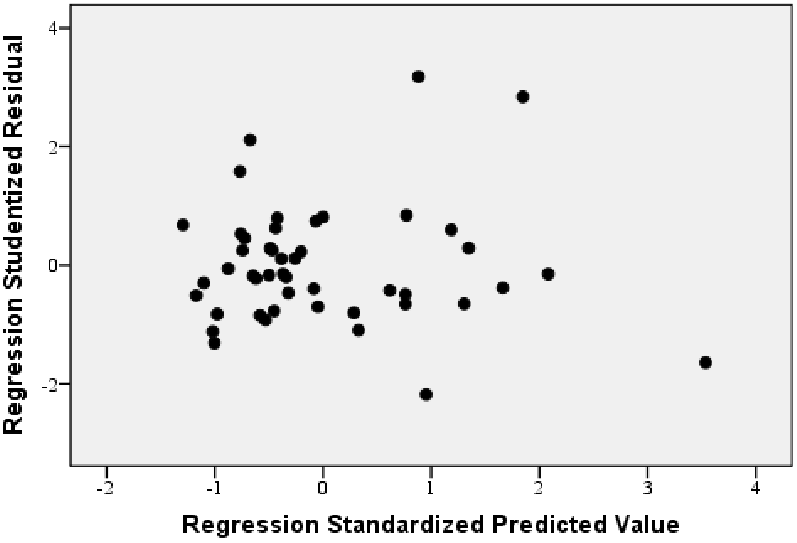


Figure 5.57: Analysis of Studentized Residuals

The next assumption deals with the constancy of the residuals across values of the independent variables, which can be tested through examination of the residuals plots. Figure 5.57 shows no pattern of increasing or decreasing residuals. This indicates homoscedasticity in the multivariate case.

The assumption of independence of residuals was checked through examining the plots of residuals and the Durbin-Watson test. From Figure 5.57, no pattern was identified among predicted value and the residual. The Durbin-Watson test value is 2.070 (see Table 5.56) in this regression model. For N = 47, number of independent variables is 3, and *p* value = 0.05, the critical values for the Durbin-Watson Test are: D_{lower} = 1.40; and D_{upper} = 1.67. The Durbin-Watson test value (2.07) is greater than D_{upper} (1.67) but less than (4- D_{upper}) (2.33), thus indicating no serial dependency among the residuals in this sample.

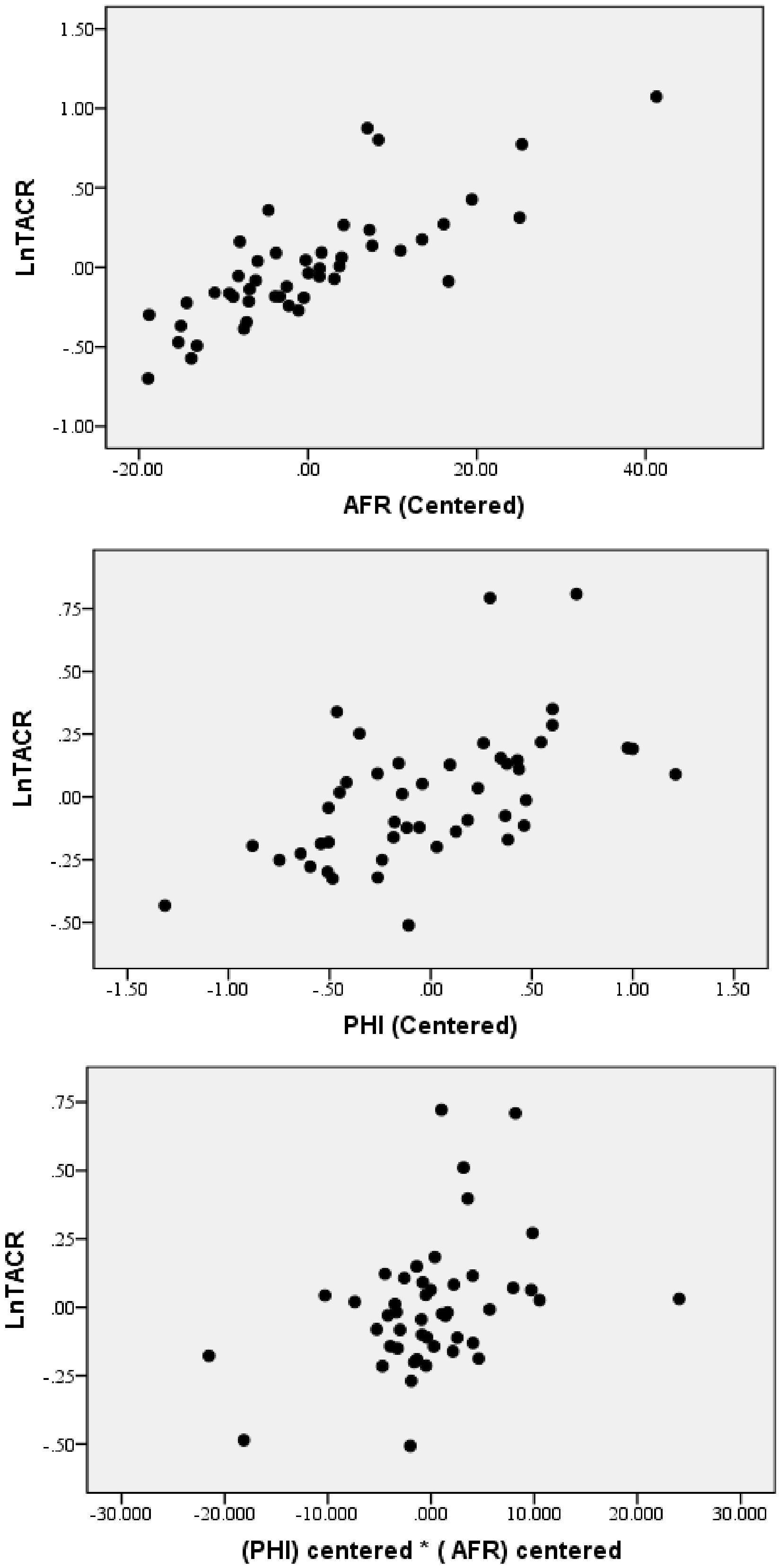


Figure 5.58: Partial Regression Plots

The final assumption is normality of the error term. Figure 5.59 presents the histogram of residuals. It shows that the mean of residuals is 0.000 and the shape is close to normal distribution. Furthermore, the normal P-P plot of regression standardized residual (see Figure 5.55) shows that the residual values are very close to the reference line, which indicates very little deviation of the expected values from the observed values. Thus, the regression variate was found to meet the assumption of normality.

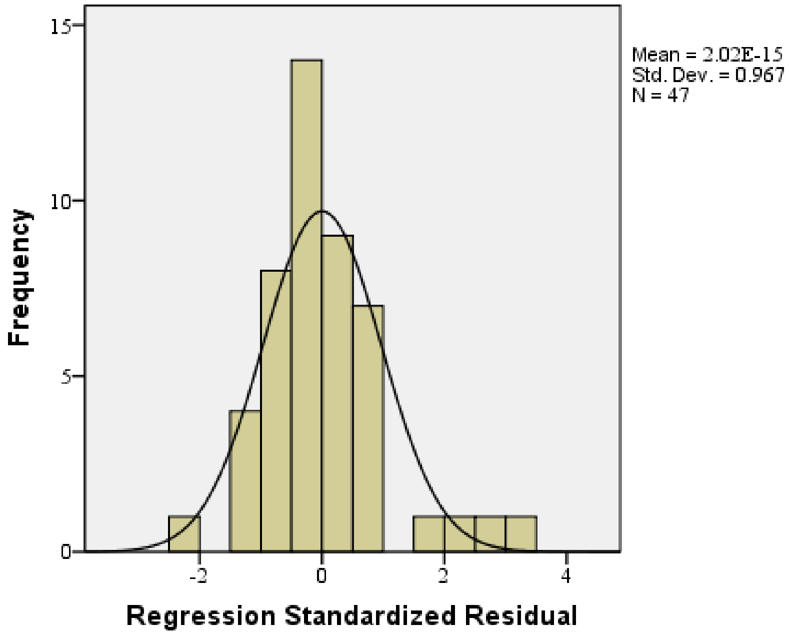


Figure 5.59: Histogram of Residuals

Eq. 5.25, Eq. 5.26, and Eq. 5.27 were combined by substituting (AFR – 21.1) for $(AFR)_c$ and (PHI – 2.90) for $(PHI)_c$, then,

$$Ln\ TACR = (-2.034+0.009 \cdot PHI) + (-0.014 + 0.013 \cdot PHI) \cdot AFR$$

$$TACR = e^{(-2.034+0.009 \cdot PHI)} \cdot e^{(-0.014 + 0.013 \cdot PHI) \cdot AFR} \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.28)}$$

Eq. 5.28 shows that the TACR curve varies with different project hazard levels. As shown in Figure 5.60, a typical TACR curve is plotted at the mean level of PHI.

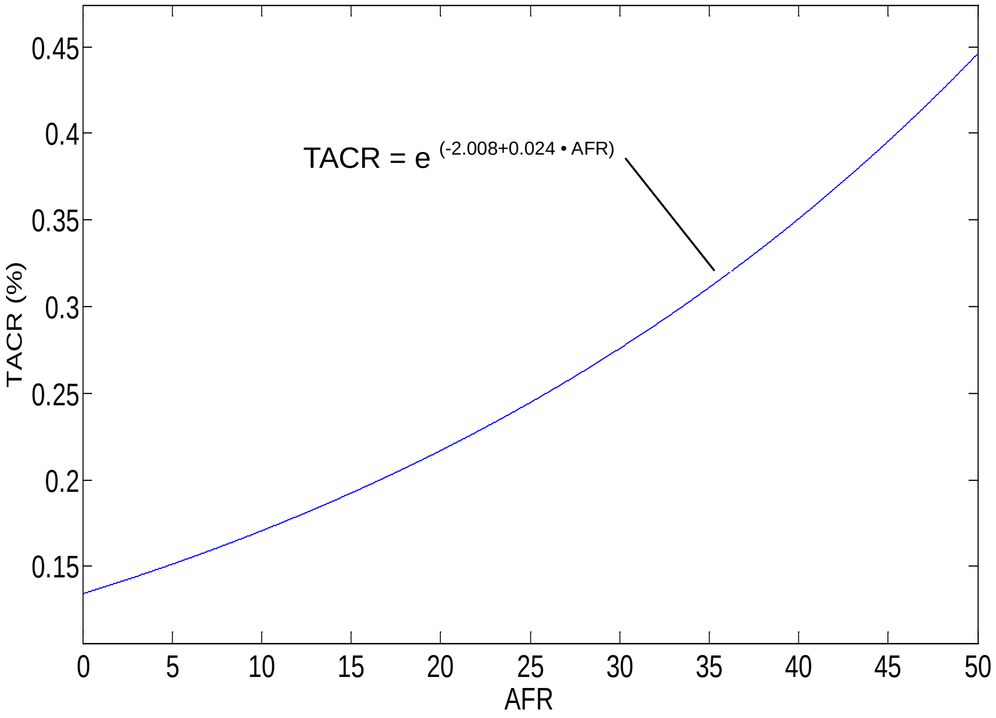


Figure 5.60: TACR Curve under Mean Level of PHI

Figure 5.60 shows a general positive tendency of the relationship between total accident costs and AFR of building projects. Eq. 5.28 further reveals the curvilinear nature of this relationship. This result is consistent with Tang *et al.*'s (1997) study, which also found an exponential relationship between total accident costs and safety performance of building projects in Hong Kong. This finding supports the hypothetical analyses of Lingard and Rowlinson (2005), Hinze (2000), Brody *et al.* (1990) and HSE (1993b), who assumed a positive and curvilinear relationship between total accident costs and the degree of OSH risk.

5.5.2.2 Validation of regression model

In the previous section, the regression model was developed to predict the TACR of building projects using AFR and PHI (see Eq. 5.28). Leave-one-out cross-validation (LOOCV) (see Section 4.4.5) was used to assess the prediction performance of the model (Eq. 5.28).

Following the method for running the leave-one-out cross-validation described in Section 4.4.5, the computation of PRESS statistic for the prediction model of TACR (Eq. 5.28) was presented in Table 5.61. Column 1 of Table 5.61 shows the observed values of y (Ln TACR), while column 2 shows the predicted values using the least-squares model developed from all the 47 data points (Eq. 5.28). Columns 3 and 4 present the computations of prediction error (e_i) and diagonal elements of the hat matrix (h_{ii}), which are used to calculate the PRESS statistic. Then

$$\mathrm{PRESS} = \sum_{i=1}^{47} \left(\frac{\mathrm{e_i}}{1-\mathrm{h_{ii}}}\right)^2 = 2.66$$

$$\mathrm{R}^2_{\mathrm{prediction}} = 1 - \frac{\mathrm{PRESS}}{\mathrm{SS_T}} = 1 - \frac{2.66}{8.797} = 0.698$$

Therefore, as compared to the 72.9% of the variability in the original data explained by the least-squares fit, this model (Eq. 5.28) could be expected to explain about 69.8% of the variability in predicting new observations. This result indicates that the

Table 5.61: Validation of the Model for Predicting TACR

	(1)	(2)	(3)	(4)
		Least-squares Fit		
Observation, *i*	Observed, y_i	Predicted, $\hat{y}_i$	Prediction Error, $e_i = y_i - \hat{y}_i$	Diagonal elements of the hat matrix, $h_{ii} = x'_i (X' X)^{-1} x_i$
1	-1.56	-1.384	-0.176	0.032
2	-0.94	-0.980	0.040	0.133
3	-1.97	-2.007	0.037	0.183
4	-0.93	-0.764	-0.166	0.067
5	-1.9	-1.696	-0.204	0.030
6	-0.21	-0.937	0.727	0.028
7	-2.12	-1.937	-0.183	0.063
8	-1.59	-1.116	-0.474	0.062
9	-1.9	-1.736	-0.164	0.042
10	-1.66	-1.445	-0.215	0.067
11	-2.04	-2.063	0.023	0.125
12	-1.61	-1.642	0.032	0.045
13	-0.54	-1.193	0.653	0.039
14	-1.83	-1.773	-0.057	0.074
15	-1.31	-1.460	0.150	0.057
16	-1.66	-1.707	0.047	0.092
17	-0.92	-1.065	0.145	0.072
18	-0.73	-0.833	0.103	0.126
19	-1.71	-1.787	0.077	0.082
20	-1.02	-1.068	0.048	0.165
21	-1.31	-1.170	-0.140	0.063
22	-2.04	-1.916	-0.124	0.058
23	-1.84	-2.104	0.264	0.126
24	-1.83	-1.658	-0.172	0.030
25	-1.61	-1.603	-0.007	0.050
26	-1.71	-1.616	-0.094	0.024
27	-1.6	-1.367	-0.233	0.038
28	-1.66	-1.766	0.106	0.039
29	-1.14	-1.052	-0.088	0.059
30	-1.35	-1.503	0.153	0.030
31	-1.61	-1.520	-0.090	0.023
32	-1.77	-1.748	-0.022	0.032
33	-1.47	-1.662	0.192	0.026
34	-1.56	-1.565	0.005	0.041
35	-1.51	-1.640	0.130	0.037
36	-1.35	-1.233	-0.117	0.043
37	-1.51	-1.568	0.058	0.023
38	-1.61	-1.684	0.074	0.027

	(1)	(2)	(3)	(4)
		Least-squares Fit		
Observation, i	Observed, y_i	Predicted, $\hat{y}_i$	Prediction Error, $e_i = y_i - \hat{y}_i$	Diagonal elements of the hat matrix, $h_{ii} = x'_i (X' X)^{-1} x_i$
39	-1.44	-1.827	0.387	0.046
40	-1.35	-1.246	-0.104	0.101
41	-1.66	-1.614	-0.046	0.047
42	-1.66	-1.574	-0.086	0.066
43	-2.1	-1.673	-0.427	0.088
44	-1.77	-1.746	-0.024	0.065
45	-1.71	-1.690	-0.020	0.042
46	-0.43	-0.502	0.072	0.447
47	-1.28	-1.784	0.504	0.045

lease-squares model predicts new observations almost as well as it fits the original data, as the “loss” in R^2 for prediction is slight (i.e., 3.1%, being 72.9% minus 69.8%). As suggested by Montgomery *et al.* (2007), the least-squares model can be seen as a satisfactory predictor if the loss in R^2 is small. Thus, the small loss (3.1%) in R^2 for prediction provides reasonably strong evidence that the predictive capability of the model (Eq. 5.28) is satisfactory.

5.5.3 Optimization of safety investments

5.5.3.1 Formula for predicting total controllable safety costs

The aim of safety costs optimization is to minimize the total controllable safety costs on workplace safety of building projects to achieve the acceptable level of safety performance. Total controllable costs (TCC) on workplace safety represent the sum of voluntary safety investments (VSI) and total accident costs (TAC). A dimensionless quantify, the Total Controllable Costs Ratio (TCCR) was used to enable the comparison of the level of total controllable safety costs among projects of different sizes. TCCR is therefore defined as

$$TCCR = \frac{TCC}{\text{Contract Sum}} \times 100\%$$

where TCC is the sum of VSI and TAC of building project. Then, TCCR is the sum of VSIR (from Eq. 5.21) and TACR (from Eq. 5.28). Thus, the formula for predicting TCCR is given in Eq. 5.29.

$$TCCR = e^{(-4.451+1.154 \bullet SCI)} \bullet AFR^{(1.273-0.405 \bullet SCI)} + e^{(-2.034+0.009 \bullet PHI)} \bullet e^{(-0.014+0.013 \bullet PHI) \bullet AFR} \quad \text{…………………….. (Eq. 5.29)}$$

where TCCR is total controllable costs ratio, SCI is safety culture index, AFR is accident frequency rate, and PHI is project hazard index.

5.5.3.2 Optimization of voluntary safety investments

Finding the minimal level of total controllable safety costs is the goal of optimization, that is to find the global minima of TCCR curve. According to the extreme value theorem (Barnett *et al.*, 2005), if a function is continuous on a closed interval, global maxima and minima exist. Furthermore, a global maximum (or minimum) either must be a local maximum (or minimum) in the interior of the domain, or must lie on the boundary of the domain (Barnett *et al.*, 2005). So a method of finding a global maximum (or minimum) is to look at all the local maxima (or minima) in the interior, and also look at the maxima (or minima) of the points on the boundary; and take the biggest (or smallest) one. Fermat's theorem gives a method to find local maxima and minima of differentiable functions by showing that every local extremum of the function is a stationary point (the function derivative is zero in that point) (Barnett *et al.,* 2005). To check if a stationary point is an extreme value and to further distinguish between a function maximum and a function minimum, it is necessary to analyze the second derivative (if it exists). As a corollary, global extrema of a function f on a domain A occurs only at boundaries, non-differentiable points, and stationary points (Barnett *et al.*, 2005).

The first derivative of TCCR curve (Eq. 5.29) is given in Eq. 5.30.

$$(\mathrm{TCCR})' = e^{(-4.451+1.154 \cdot \mathrm{SCI})} \cdot (1.273 - 0.405 \cdot \mathrm{SCI}) \cdot \mathrm{AFR}^{(0.273- 0.405 \cdot \mathrm{SCI})}$$

$$+ e^{(-2.034+0.009 \cdot \mathrm{PHI})} \cdot (-0.014 + 0.013 \cdot \mathrm{PHI}) \cdot e^{(-0.014 + 0.013 \cdot \mathrm{PHI}) \cdot \mathrm{AFR}}$$

…………..………………..… (Eq. 5.30)

The second derivative of TCCR curve (Eq. 5.29) is given in Eq. 5.31.

(TCCR)"

$$= e^{(-4.451+1.154 \cdot SCI)} \cdot (1.273–0.405 \cdot SCI) \cdot (0.273–0.405 \cdot SCI) \cdot AFR^{(-0.727–0.405 \cdot SCI)} + e^{(-2.034+0.009 \cdot PHI)} \cdot (-0.014 + 0.013 \cdot PHI)^2 \cdot e^{(-0.014 + 0.013 \cdot PHI) \cdot AFR}$$

…………………….……..… (Eq. 5.31)

As shown in Eq. 5.29, different TCCR curves would be obtained with different safety culture levels and project hazard levels. The TCCR curves were plotted at three typical values of SCI: the mean value of SCI; a low value of SCI (1 standard deviation below the mean value); and a high value of SCI (1 standard deviation above the mean value). Three typical values of PHI: the mean value of PHI, a low value of PHI (1 standard deviation below the mean value), and a high value of PHI (1 standard deviation above the mean value) were also used to plot the curves. A total of nine TCCR curves are generated and analyzed as below.

- Scenario 1: SCI = mean (SCI) = 3.58; PHI = -1 dev (PHI) = 2.36

In this scenario, safety culture level is set at the mean value (i.e., SCI = mean (SCI) = 3.58), and project hazard level is set at a low value (i.e., PHI = -1 dev (PHI) = 2.36).

Then, by substituting 3.58 for SCI and 2.36 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 1 are given in Eq. 5.32, Eq. 5.33, and Eq. 5.34, respectively. The VSIR, TACR, and TCCR curves are plotted in Figure 5.61.

$$VSIR = 0.726 \bullet AFR^{(-0.177)} \quad \text{(Eq. 5.32)}$$

$$TACR = 0.134 \bullet e^{0.017 \bullet AFR} \quad \text{(Eq. 5.33)}$$

$$TCCR = 0.726 \bullet AFR^{(-0.177)} + 0.134 \bullet e^{0.017 \bullet AFR} \quad \text{(Eq. 5.34)}$$

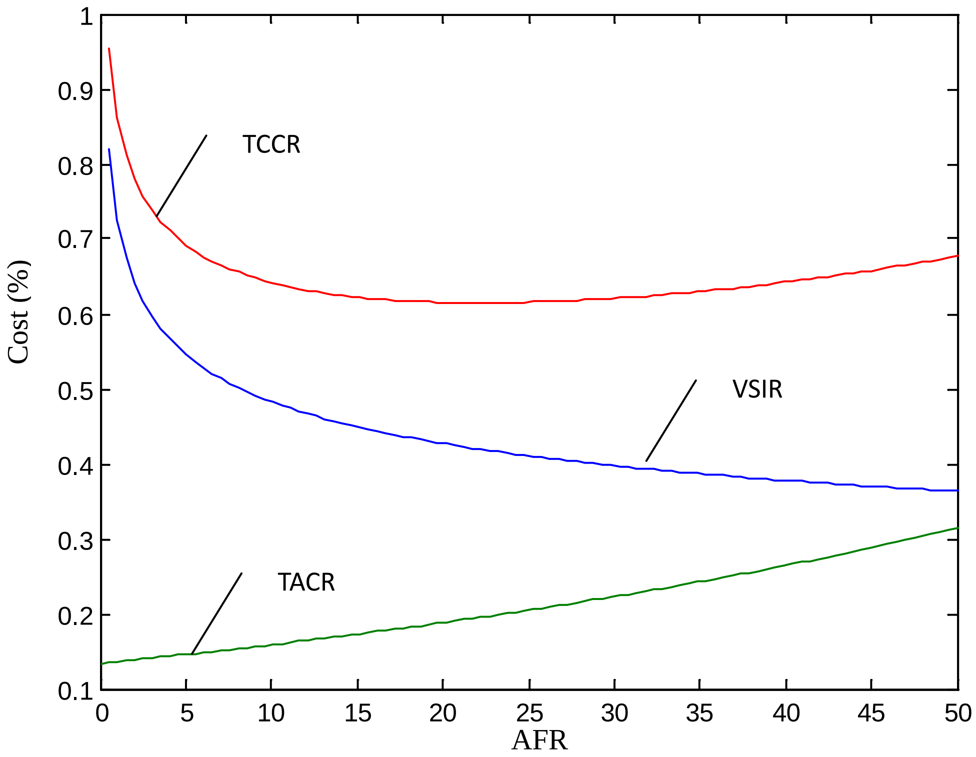


Figure 5.61: Optimization of Safety Costs for Scenario 1

The first derivative of TCCR curve (Eq. 5.34) is given in Eq. 5.35.

$$(TCCR)' = -0.129 \bullet AFR^{-1.177} + 0.0022 \bullet e^{0.017 \bullet AFR} \quad \text{(Eq. 5.35)}$$

The second derivative of TCCR curve (Eq. 5.34) is given in Eq. 5.36.

$(TCCR)'' = 0.152 \cdot AFR^{-2.177} + 0.00003 \cdot e^{0.017 \cdot AFR}$……………….……… (Eq. 5.36)

Eq. 5.36 shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)’ = 0

Then, AFR = 22.85

Substituting 22.85 for AFR in Eq. 5.32 and Eq. 5.33 produces the following:

VSIR = 0.418%

TACR = 0.196%.

Thus, the optimum level of VSI is 0.418% of total contract sum of a building project, when SCI is at the mean level and PHI is at the low level.

- Scenario 2: SCI = mean (SCI) = 3.58; PHI = mean (PHI) = 2.9

In this scenario, both safety culture level and project hazard level are set at the mean value (i.e., SCI = mean (SCI) = 3.58; PHI = mean (PHI) = 2.9).

Then, by substituting 3.58 for SCI and 2.9 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 2 are given in Eq. 5.37, Eq. 5.38, and Eq. 5.39, respectively. The VSIR, TACR, and TCCR curves under scenario 2 are plotted in Figure 5.62.

$$VSIR = 0.726 \bullet AFR^{(-0.177)} \ldots\ldots\ldots\ldots \text{(Eq. 5.37)}$$

$$TACR = 0.134 \bullet e^{0.024 \bullet AFR} \ldots\ldots\ldots\ldots \text{(Eq. 5.38)}$$

$$TCCR = 0.726 \bullet AFR^{(-0.177)} + 0.134 \bullet e^{0.024 \bullet AFR} \ldots\ldots\ldots\ldots \text{(Eq. 5.39)}$$

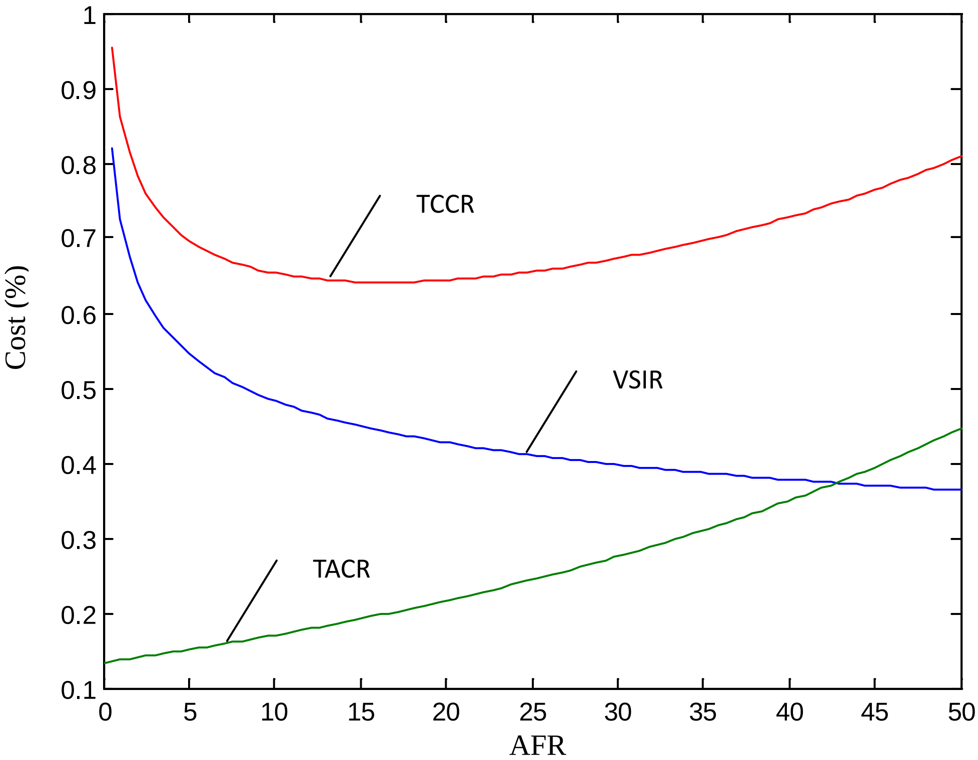


Figure 5.62: Optimization of Safety Costs for Scenario 2

The first derivative and second derivative of TCCR curve (Eq. 5.39) are given in Eq. 5.40 and Eq. 5.41, respectively.

$(TCCR)' = -0.129 \cdot AFR^{-1.177} + 0.0032 \cdot e^{0.024 \cdot AFR}$…………..…………. (Eq. 5.40)

$(TCCR)'' = 0.152 \cdot AFR^{-2.177} + 0.0001 \cdot e^{0.024 \cdot AFR}$…………………….. (Eq. 5.41)

Eq. 5.41 shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)' = 0

Then, AFR = 16.51

Substituting 16.51 for AFR in Eq. 5.37 and Eq. 5.38 produces the following:

VSIR = 0.442%

TACR = 0.199%.

Thus, the optimum level of VSI is 0.442% of total contract sum of a building project, when SCI and PHI are at their mean level.

- Scenario 3: SCI = mean (SCI) = 3.58; PHI = +1 dev (PHI) = 3.44

In this scenario, safety culture level is set at the mean value (i.e., SCI = mean (SCI) = 3.58), and project hazard level is set at a high value (i.e., PHI = +1 dev (PHI) = 3.44).

Then, by substituting 3.58 for SCI and 3.44 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 3 are given in Eq. 5.42, Eq. 5.43, and Eq. 5.44, respectively. The VSIR, TACR, and TCCR curves under scenario 3 are plotted in Figure 5.63.

$VSIR = 0.726 \bullet AFR^{(-0.177)}$ …………….……….……………………….…. (Eq. 5.42)

$TACR = 0.135 \bullet e^{0.031 \bullet AFR}$ ….……………………………………………………. (Eq. 5.43)

$TCCR = 0.726 \bullet AFR^{(-0.177)} + 0.135 \bullet e^{0.031 \bullet AFR}$ ………………………….……. (Eq. 5.44)

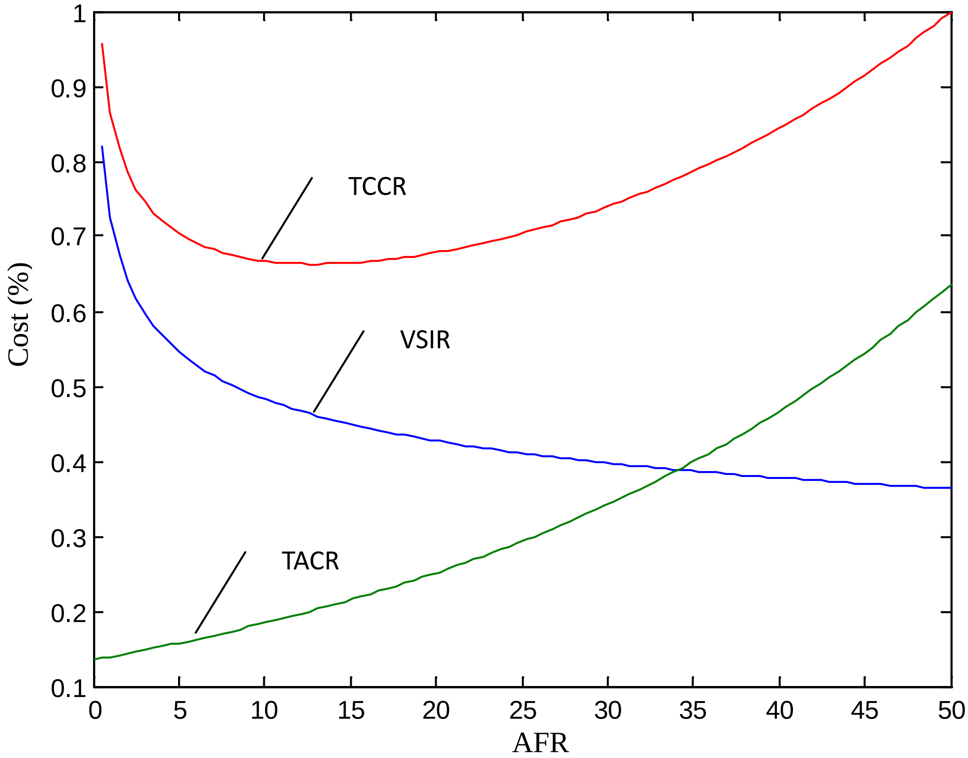


Figure 5.63: Optimization of Safety Costs for Scenario 3

The first derivative and second derivative of TCCR curve (Eq. 5.44) are given in Eq. 5.45 and Eq. 5.46, respectively.

$(TCCR)' = -0.129 \cdot AFR^{-1.177} + 0.0041 \cdot e^{0.031 \cdot AFR}$………….…………. (Eq. 5.45)

$(TCCR)'' = 0.152 \cdot AFR^{-2.177} + 0.0001 \cdot e^{0.031 \cdot AFR}$…………………….. (Eq. 5.46)

Eq. (7.32) shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)’ = 0

Then, AFR = 13.22

Substituting 13.22 for AFR in Eq. 5.42 and Eq. 5.43 produces the following:

VSIR = 0.46%

TACR = 0.203%.

Thus, the optimum level of VSI is 0.46% of total contract sum of a building project, when SCI is at the mean level and PHI is at the high level.

- Scenario 4: SCI = -1 dev (SCI) = 3.40; PHI = -1 dev (PHI) = 2.36

In this scenario, both safety culture level and project hazard level are set at a low value (i.e., SCI = -1 dev (SCI) = 3.40; PHI = -1 dev (PHI) = 2.36).

Then, by substituting 3.4 for SCI and 2.36 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 4 are given in Eq. 5.47, Eq. 5.48, and Eq. 5.49, respectively. The VSIR, TACR, and TCCR curves under scenario 4 are plotted in Figure 5.64.

$$VSIR = 0.59 \bullet AFR^{(-0.104)} \qquad \text{(Eq. 5.47)}$$

$$TACR = 0.134 \bullet e^{0.017 \bullet AFR} \qquad \text{(Eq. 5.48)}$$

$$TCCR = 0.59 \bullet AFR^{(-0.104)} + 0.134 \bullet e^{0.017 \bullet AFR} \qquad \text{(Eq. 5.49)}$$

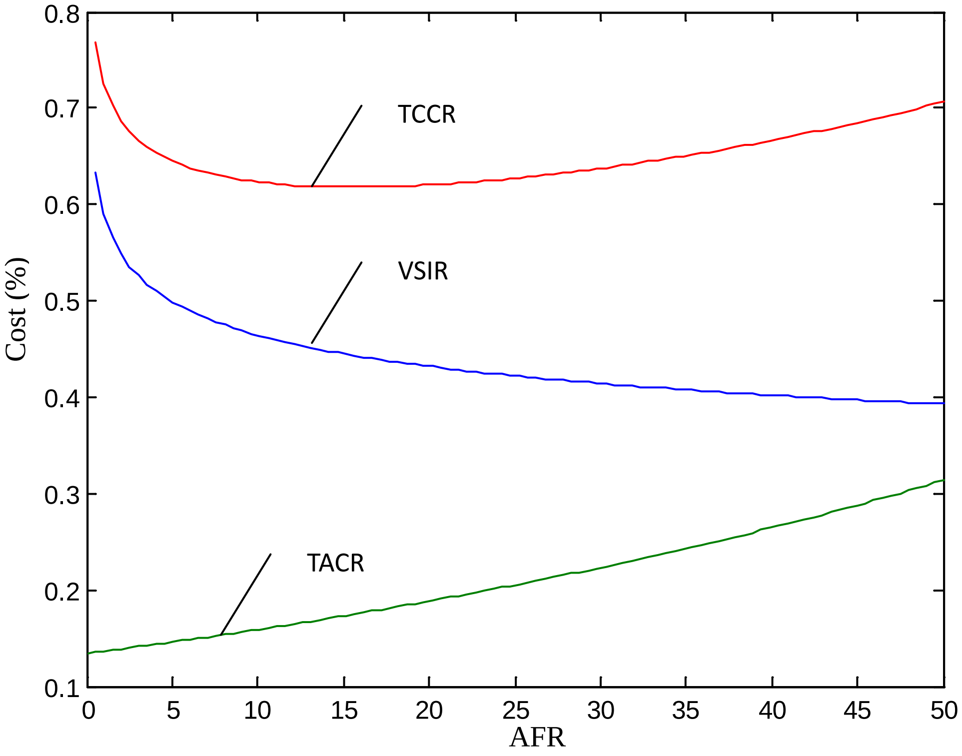


Figure 5.64: Optimization of Safety Costs for Scenario 4

The first derivative and second derivative of TCCR curve (Eq. 5.49) are given in Eq. 5.50 and Eq. 5.51, respectively.

$(TCCR)' = -0.061 \cdot AFR^{-1.104} + 0.0022 \cdot e^{0.017 \cdot AFR}$………….…………. (Eq. 5.50)

$(TCCR)'' = 0.068 \cdot AFR^{-2.104} + 0.00003 \cdot e^{0.017 \cdot AFR}$…………………….. (Eq. 5.51)

Eq. (5.51) shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)' = 0

Then, AFR = 15.88.

Substituting 15.88 for AFR in Eq. 5.47 and Eq. 5.48 produces the following:

VSIR = 0.443%

TACR = 0.174%

Thus, the optimum level of VSI is 0.443% of total contract sum of a building project, when both the SCI and PHI are at the low level.

- Scenario 5: SCI = -1 dev (SCI) = 3.40; PHI = mean (PHI) = 2.9

In this scenario, safety culture level is set at a low value (i.e., SCI = -1 dev (SCI) = 3.40), and project hazard level is set at the mean value (i.e., PHI = mean (PHI) = 2.9).

Then, by substituting 3.4 for SCI and 2.9 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 5 are given in Eq. 5.52, Eq. 5.53, and Eq. 5.54, respectively. The VSIR, TACR, and TCCR curves under scenario 5 are plotted in Figure 5.65.

$VSIR = 0.59 \bullet AFR^{(-0.104)}$……………..……..………………………..…. (Eq. 5.52)

$TACR = 0.134 \bullet e^{0.024 \bullet AFR}$…..…..…..…..…..…..…..…..………………………. (Eq. 5.53)

$TCCR = 0.59 \bullet AFR^{(-0.104)} + 0.134 \bullet e^{0.024 \bullet AFR}$……………………….……. (Eq. 5.54)

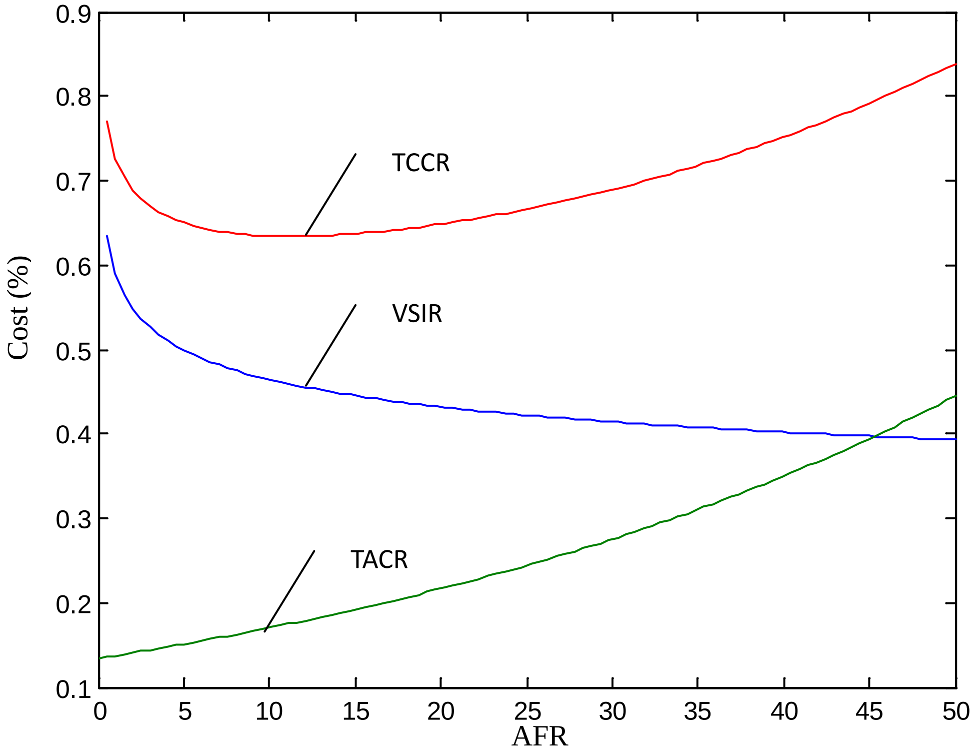


Figure 5.65: Optimization of Safety Costs for Scenario 5

The first derivative and second derivative of TCCR curve (Eq. 5.54) are given in Eq. 5.55 and Eq. 5.56, respectively.

$(TCCR)' = -0.061 \cdot AFR^{-1.104} + 0.0032 \cdot e^{0.024 \cdot AFR}$…………..…………. (Eq. 5.55)

$(TCCR)'' = 0.067 \cdot AFR^{-2.104} + 0.0001 \cdot e^{0.024 \cdot AFR}$…………………….. (Eq. 5.56)

Eq. 5.56 shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)’ = 0

Then, AFR = 11.30

Substituting 11.30 for AFR in Eq. 5.52 and Eq. 5.53 produced the following:

VSIR = 0.459%

TACR = 0.176%.

Thus, the optimum level of VSI is 0.459% of total contract sum of a building project, when SCI is at the low level and PHI is at the mean level.

- Scenario 6: SCI = -1 dev (SCI) = 3.40; PHI = +1 dev (PHI) = 3.44

In this scenario, safety culture level is set at a low value (i.e., SCI = -1 dev (SCI) = 3.40), and project hazard level is set at a high value (i.e., PHI = +1 dev (PHI) = 3.44).

Then, by substituting 3.4 for SCI and 3.44 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 6 are given in Eq. 5.57, Eq. 5.58, and Eq. 5.59, respectively. The VSIR, TACR, and TCCR curves under scenario 6 are plotted in Figure 5.66.

$$VSIR = 0.59 \bullet AFR^{(-0.104)} \quad \text{(Eq. 5.57)}$$

$$TACR = 0.135 \bullet e^{0.031 \bullet AFR} \quad \text{(Eq. 5.58)}$$

$$TCCR = 0.59 \bullet AFR^{(-0.104)} + 0.135 \bullet e^{0.031 \bullet AFR} \quad \text{(Eq. 5.59)}$$

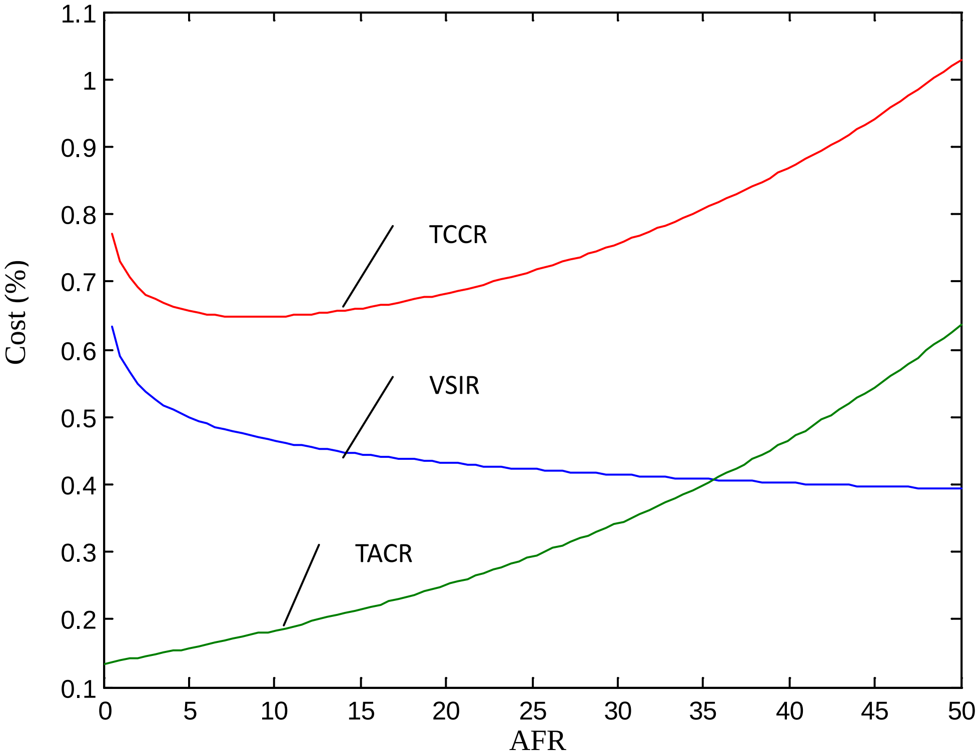


Figure 5.66: Optimization of Safety Costs for Scenario 6

The first derivative and second derivative of TCCR curve (Eq. 5.59) are given in Eq. 5.60 and Eq. 5.61, respectively.

$(TCCR)' = -0.061 \cdot AFR^{-1.104} + 0.0041 \cdot e^{0.031 \cdot AFR}$………….…………. (Eq. 5.60)

$(TCCR)'' = 0.067 \cdot AFR^{-2.104} + 0.0001 \cdot e^{0.031 \cdot AFR}$…………………….. (Eq. 5.61)

Eq. (5.61) shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)' = 0

Then, AFR = 8.97

Substituting AFR = 8.97 for AFR in Eq. 5.57 and Eq. 5.58 produces the following:

VSIR = 0.47%

TACR = 0.178%.

Thus, the optimum level of VSI is 0.47% of total contract sum of a building project, when SCI is at the low level and PHI is at the mean level.

- Scenario 7: SCI = +1 dev (SCI) = 3.76; PHI = -1 dev (PHI) = 2.36.

In this scenario, safety culture level is set at a high value (i.e., SCI = +1 dev (SCI) = 3.76), and project hazard level is set at a low value (i.e., PHI = -1 dev (PHI) = 2.36).

Then, by substituting 3.76 for SCI and 2.36 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 7 are given in Eq. 5.62, Eq. 5.63, and Eq. 5.64, respectively. The VSIR, TACR, and TCCR curves under scenario 7 are plotted in Figure 5.67.

$VSIR = 0.894 \cdot AFR^{(-0.25)}$ ……………..………..……………………..…. (Eq. 5.62)

$TACR = 0.134 \cdot e^{0.017 \cdot AFR}$ ……………………………..………………………. (Eq. 5.63)

$TCCR = 0.894 \cdot AFR^{(-0.25)} + 0.134 \cdot e^{0.017 \cdot AFR}$ ……………………….……. (Eq. 5.64)

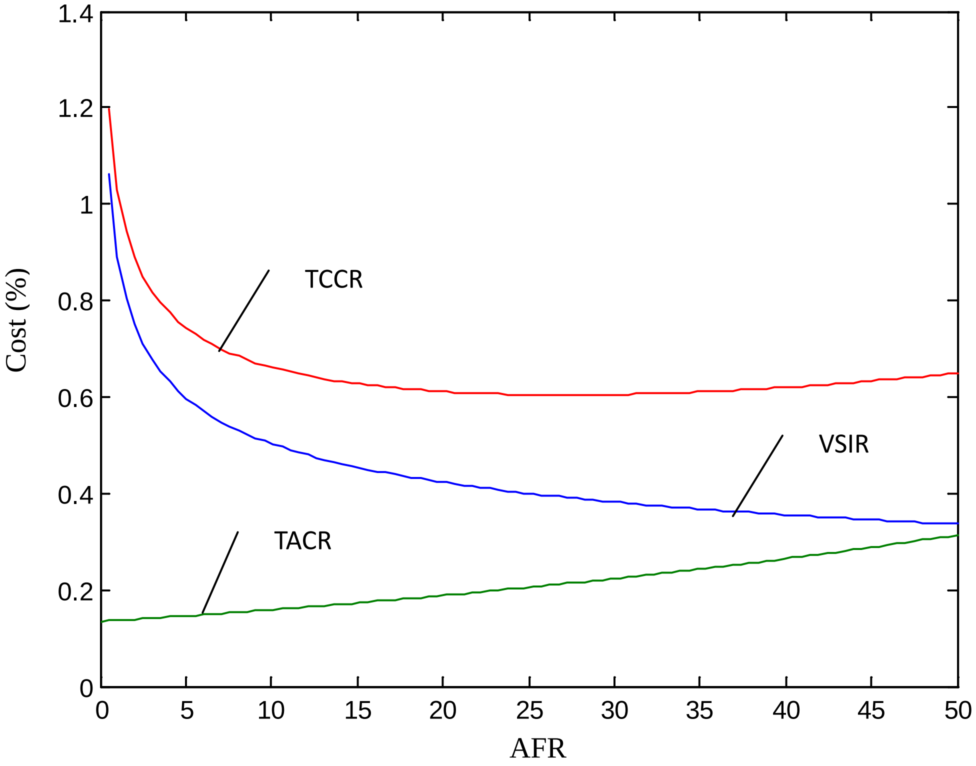


Figure 5.67: Optimization of Safety Costs for Scenario 7

The first derivative and second derivative of TCCR curve (Eq. 5.64) are given in Eq. 5.65 and Eq. 5.66, respectively.

$(TCCR)' = -0.223 \cdot AFR^{-1.25} + 0.0022 \cdot e^{0.017 \cdot AFR}$………….…………. (Eq. 5.65)

$(TCCR)'' = 0.279 \cdot AFR^{-2.25} + 0.00003 \cdot e^{0.017 \cdot AFR}$…………………….. (Eq. 5.66)

Eq. 5.66 shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)' = 0

Then, AFR = 27.64.

Substituting 27.64 for AFR in Eq. 5.62 and Eq. 5.63 produces the following:

VSIR = 0.39%

TACR = 0.212%.

Thus, the optimum level of VSI is 0.39% of total contract sum of a building project, when SCI is at the high level and PHI is at the low level.

- Scenario 8: SCI = +1 dev (SCI) = 3.76; PHI = mean (PHI) = 2.9.

In this scenario, safety culture level is set at a high value (i.e., SCI = +1 dev (SCI) = 3.76), and project hazard level is set at the mean value (i.e., PHI = mean (PHI) = 2.9).

Then, by substituting 3.76 for SCI and 2.9 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 8 are given in Eq. 5.67, Eq. 5.68, and Eq. 5.69, respectively. The VSIR, TACR, and TCCR curves under scenario 8 are plotted in Figure 5.68.

$$VSIR = 0.894 \bullet AFR^{(-0.25)} \quad \text{(Eq. 5.67)}$$

$$TACR = 0.134 \bullet e^{0.024 \bullet AFR} \quad \text{(Eq. 5.68)}$$

$$TCCR = 0.894 \bullet AFR^{(-0.25)} + 0.134 \bullet e^{0.024 \bullet AFR} \quad \text{(Eq. 5.69)}$$

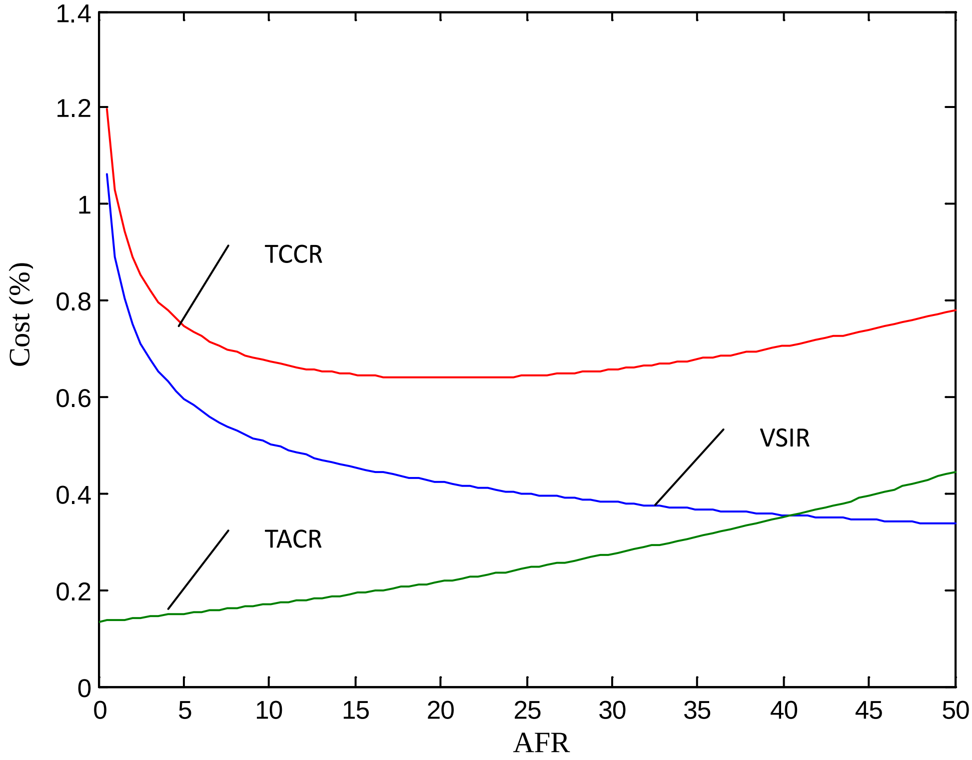


Figure 5.68: Optimization of Safety Costs for Scenario 8

The first derivative and second derivative of TCCR curve (Eq. 5.69) are given in Eq. 5.70 and Eq. 5.71, respectively.

$(TCCR)' = -0.223 \cdot AFR^{-1.25} + 0.0032 \cdot e^{0.024 \cdot AFR}$………….…………. (Eq. 5.70)

$(TCCR)'' = 0.279 \cdot AFR^{-2.25} + 0.0001 \cdot e^{0.024 \cdot AFR}$…………………….. (Eq. 5.71)

Eq. 5.71 shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)' = 0

Then, AFR = 20.22.

Substituting 20.22 for AFR in Eq. 5.67 and Eq. 5.68 produces the following:

VSIR = 0.422%

TACR = 0.217%.

Thus, the optimum level of VSI is 0.422% of total contract sum of a building project, when SCI is at the high level and PHI is at the mean level.

- Scenario 9: SCI = +1 dev (SCI) = 3.76; PHI = +1 dev (PHI) = 3.44

In this scenario, both safety culture level and project hazard level are set at a high value (i.e., SCI = +1 dev (SCI) = 3.76; PHI = +1 dev (PHI) = 3.44).

Then, by substituting 3.76 for SCI and 3.44 for PHI in Eq. 5.21, Eq. 5.28, and Eq. 5.29, the VSIR curve, TACR curve, and TCCR curve for scenario 9 are given in Eq. 5.72, Eq. 5.73, and Eq. 5.74, respectively. The VSIR, TACR, and TCCR curves under scenario 9 are plotted in Figure 5.69.

$$VSIR = 0.894 \bullet AFR^{(-0.25)} \quad \text{(Eq. 5.72)}$$

$$TACR = 0.135 \bullet e^{0.031 \bullet AFR} \quad \text{(Eq. 5.73)}$$

$$TCCR = 0.894 \bullet AFR^{(-0.25)} + 0.135 \bullet e^{0.031 \bullet AFR} \quad \text{(Eq. 5.74)}$$

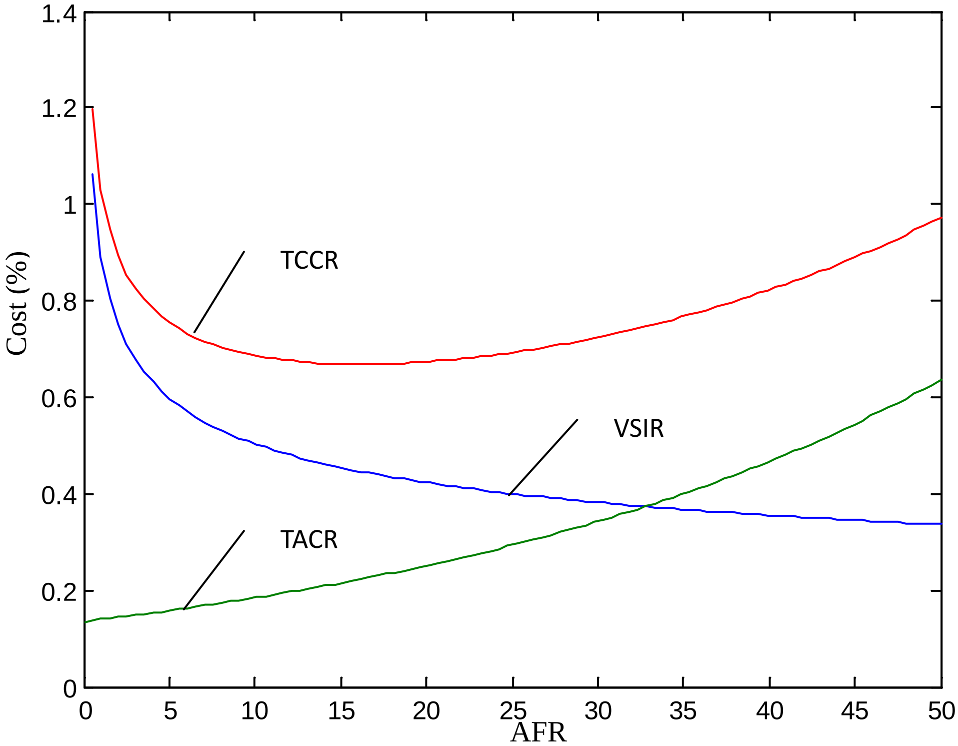


Figure 5.69: Optimization of Safety Costs for Scenario 9

The first derivative and second derivative of TCCR curve (Eq. 5.74) are given in Eq. 5.75 and Eq. 5.76, respectively.

$(TCCR)' = -0.223 \cdot AFR^{-1.25} + 0.0041 \cdot e^{0.031 \cdot AFR}$ …………..…………. (Eq. 5.75)

$(TCCR)'' = 0.278 \cdot AFR^{-2.25} + 0.0001 \cdot e^{0.031 \cdot AFR}$ …………………….. (Eq. 5.76)

Eq. 5.76 shows that the sign of the second derivative of TCCR is positive whatever the value of AFR. This indicates that the stationary point (the function derivative is zero in that point) of TCCR curve is the function minimum.

Set, (TCCR)' = 0

Then, AFR = 16.32.

Substituting 16.32 for AFR in Eq. 5.72 and Eq. 5.73 produces the following:

VSIR = 0.445%

TACR = 0.223%.

Thus, the optimum level of VSI is 0.445% of total contract sum of a building project, when both the SCI and PHI are at the high level.

The results of safety costs optimization under 9 typical scenarios are discussed in Chapter 6.

5.6 Summary

This chapter analysed the data collected. Section 5.3 examined the relationships among safety investments, safety culture, project hazard level, accident frequency rate and accident severity rate. The results of bivariate correlation analysis (see Section

5.3.1) provide evidence to support hypotheses 1.1 (i.e., safety performance of building projects varies positively with the level of safety investments), 1.2 (i.e., safety performance of building projects varies positively with the level of safety culture) and 1.3 (i.e., safety performance of building projects varies inversely with the project hazard level). The results of moderation analysis and mediation analysis show that: (1) the effect of basic safety investments on safety performance is moderated by project hazard level and safety culture; (2) the effect of total safety investments on safety performance is mediated by safety culture; (3) the effect of voluntary safety investments on safety performance is mediated by safety culture; (4) the effect of safety culture on safety performance is moderated by project hazard level; and (5) the relationship between accident frequency rate and accident severity rate is moderated by project hazard level. The above results provide evidence to support hypotheses 1.4 (i.e., the effect of safety investments on safety performance varies with project hazard level) and 1.5 (i.e., the effect of safety investments on safety performance varies with safety culture level).

Section 5.4 examined the costs of accidents to building projects (objective 3 of this study). The results (see Section 5.4.1) show that the average direct accident costs, indirect accident costs and total accident costs of building projects account for 0.165%, 0.086%, and 0.25% of total contract sum, respectively. The result of bivariate correlation analysis shows that the total accident costs of building projects vary positively with accident frequency rate and project hazard level, thus supporting hypotheses 2.1 and 2.2. The result of moderation analysis (see Section 5.4.3) shows that the relationship between the number of accidents and the costs of accidents is dependent on the project hazard level. There is a stronger positive effect of accident frequency rate on total accident costs under higher project hazard level. This result provides empirical evidence to support hypothesis 2.4 that the effect of accident frequency rate on the total accident costs of a building project varies with the project hazard level. No evidence was found to support the hypotheses 2.3 (i.e., the total accident costs of a building project vary with the project characteristics).

Section 5.5 investigated the optimization of safety investments (Objective 4 of this study). In this section, the models for predicting VSIR (Eq. 5.21) and TACR (Eq. 5.28) were developed and validated. The model for predicting TCCR (Eq. 5.29) was constructed through the combination of VSIR curve (Eq. 5.21) and TACR curve (Eq. 5.28). The VSIR, TACR and TCCR curves were plotted at three typical values of SCI: the mean value; a low value (1 standard deviation below the mean value); and a high value (1 standard deviation above the mean value); as well as three typical values of PHI: the mean value; a low value (1 standard deviation below the mean value); and a high value (1 standard deviation below the mean value). The optimization results under 9 typical scenarios (see Section 5.5.3) show that the financially optimum level of voluntary safety investments coincide with the minimal level of total controllable safety costs of building projects. It was found that the financially optimum level of voluntary safety investments of building projects in Singapore is about 0.44% of the contract sum (i.e., when both safety culture and project hazard are at the mean level).

CHAPTER SIX

DISCUSSION OF RESULTS

CHAPTER 6: DISCUSSION OF RESULTS

6.1 Introduction

Having analysed the data and tested the hypotheses in Chapter 5, this chapter discusses the implications of these empirical results. Section 6.2 discusses the relationship between the two safety performance indicators. Section 6.3 and Section 6.4 discuss the effects of safety investments on safety performance. Then, based on the empirical findings in Chapter 5 and the discussions in Sections 6.2, 6.3 and 6.4, a model for determining safety performance of building projects is proposed in Section 6.5. Finally, the results of safety investments optimization are discussed in Section 6.6.

6.2 Safety performance indicators

In Singapore, both AFR and ASR are used by the Ministry of Manpower (MOM) to measure workplace safety performance. As shown from the formulae (see Section 4.3.1), AFR reflects the total number of accidents in a project, and ASR collects information on both total number of accidents in a project and the number of man-days lost due to each accident.

The results of bivariate correlation analysis (see Section 5.3.1) show that ASR is significantly ($p < 0.05$) correlated with safety culture level ($r = -0.46$) and project hazard level (r =0.363), while AFR is significantly (p <0.05) correlated with total safety investments (r =-0.436), basic safety investments (r =-0.282), voluntary safety investments (r =-0.539), and safety culture level (r =-0.439). This result implies that frequency of accidents is related to human effort (i.e. safety investments and safety culture), while severity of accidents tends to be affected by not only human effort (i.e. cultivation of safety culture) but also initial project conditions (i.e. project hazard level).

Furthermore, the result of moderated regression (see Section 5.3.6) shows that the relationship between AFR and ASR is moderated by project hazard level. This result indicates that the relationship between frequency and severity of accidents becomes stronger when the hazard level of a project is higher. A possible reason is that higher level of project hazard (e.g., higher heights of building and more work in confined spaces) tends to be associated with greater chance of serious injuries. Table 5.53 (see Section 5.3.6) shows that the simple slope for ASR on AFR is not significant when project hazard level is low (-1 Std. Dev.). This indicates that accident severity rate might be low even if the accident frequency rate is high for those projects with low hazard level. It implies that, in low hazard conditions, frequent occurrence of accidents does not necessarily result in severe injuries, possibly due to the role of “blind chance”. This finding supports the arguments put forward by the U.S. Department of Labor (1955) that blind chance usually plays a greater part in determining seriousness of an injury than it does in determining how frequently accidental injuries occur. This is also consistent with Lingard and Rowlinson’s (2005) finding that accidents prevention strategies must take into account the frequent occurrence of incidents which have the potential to cause serious injury but which do not do so, largely due to blind chance.

The implication of the findings is that safety performance indicators that focus on serious injuries may fail to show the true effectiveness of safety efforts. Therefore, it could be argued that accident frequency rate tends to be more directly related to the effectiveness of human efforts in accident prevention activities than accident severity does due to the role of project hazard level and blind chance in determining accidents severity rate.

The findings of this study suggest that the use of different safety performance indicators may partly explain why the findings of the relationship between safety investments and safety performance were inconsistent in previous studies. For example, Crites (1995) used Loss Workday Rate (WDR) as the safety performance indicator to compare safety performance with the size and funding of formal safety programs over an 11-year period (1980-1990), while Tang *et al.* (1997) investigated the relationship between safety investments and safety performance of building projects using Accident Occurrence Index (AOI) as the indicator of safety performance. Crites (1995) found that safety performance was independent of – or even inversely related to – safety investment, whilst Tang *et al.* (1997) found a weak correlation between safety investments and safety performance. The results of this study further confirmed the possible discrepancies of the findings due to the use of different safety performance indicators. For example, the correlation between total safety investments and safety performance (see Figure 5.14 in Section 5.3.1) indicates that the level of safety investments has an impact on AFR, while no impact on ASR. Therefore, it is advisable for researchers in the area of construction safety to draw conclusions of their research with consideration of the possible discrepancies incurred by the selection of safety performance indicators.

6.3 Voluntary safety investments and safety performance

6.3.1 Direct effect of voluntary safety investments on safety performance

Total safety investments (TSI) comprise two categories: basic safety investments (BSI); and voluntary safety investments (VSI) (see Section 4.3.1). It was found that different types of safety investments have different effects on safety performance of building projects (see Section 5.3.1). Figure 5.14 (see Section 5.3.1) shows that the effect of VSIR on AFR ($r = -0.539$, $p < 0.05$) is more significant than that of BSIR on AFR ($r = -0.282$, $p < 0.05$).

Based on the definition of basic safety investments (see Section 4.3.1), the investments in basic safety measures (e.g., employment of safety professionals, provision of safety equipments, and enforcement of formal safety training courses) are largely determined by industry and government regulations and construction process to maintain minimal safety standard. One possible reason for the relatively weaker effect of BSIR on AFR could be that the contractors have to invest in certain basic safety prevention activities even if some of these activities could be ineffective or inefficient for their projects. This is supported by Hallowell's (2010) study, where it was found that employment of full-time safety professionals (i.e. individuals with formal construction safety and health experience and/or education) was among the least cost-effective elements of a safety programme. In comparison with the enforcement nature of basic safety measures, the investments in voluntary safety measures (e.g., accident investigation, safety inspections, safety committee, safety promotion and incentives and in-house safety training and orientation) are the result of contractors' voluntary selection and therefore reflect the willingness of contractors to improve safety standard of their projects.

Consequently, a possible reason for the relatively stronger effect of VSI on safety performance could be that contractors may choose to invest in those activities that would be considered to be more effective or efficient and determine the level of investments based on the specific needs of individual projects. This finding is consistent with the results of many studies (Aksorn and Hadikusumo, 2008; Findley *et al.,* 2004; Poon *et al.*, 2000; Tam and Fung, 1998; Jaselskis *et al.,* 1996), where the researchers examined and compared the effectiveness of various safety measures. These studies revealed that safety inspections and investigations (Aksorn and

Hadikusumo, 2008; Poon *et al.*, 2000; Jaselskis *et al.*, 1996; Tam and Fung, 1998), safety committees and meetings (Tam and Fung, 1998; Jaselskis *et al.*, 1996), safety promotions and incentives (Aksorn and Hadikusumo, 2008; Tam and Fung, 1998; Jaselskis *et al.*, 1996), and in-house safety trainings and orientations (Findley *et al.*, 2004; Tam and Fung, 1998) were among the most effective safety measures for construction safety performance improvement. This finding also suggests that basic safety investments (e.g., employment of safety professionals, provision of personal protection equipments and enforcement of formal safety training courses) are less cost-effective than voluntary safety investments (e.g., accident investigation, safety inspections, safety committee, safety incentives and in-house safety training and orientation).

6.3.2 Indirect effect of voluntary safety investments on safety performance

The result of mediation analysis for the effects of total safety investments on safety performance (see Section 5.3.2) shows that the effects of total safety investments on safety performance (measured by AFR) are partially mediated by safety culture level. It indicates that some of the effects of total safety investments on AFR are direct, while some are indirect. Teo and Feng (2011) found that some kinds of safety investments like the time invested in accident prevention activities (e.g., the time invested in participation in safety training and orientation, the time invested in emergency response drills, the time invested in safety meetings and inspections, and the time invested in accident investigations and other activities) do not produce a direct impact on safety performance, while they contribute to the cultivation of safety culture and then indirectly influence safety performance through the effect of safety culture. Thus, the total safety investment was found to have its impact on safety performance by partly going through the mediator, safety culture.

This process could be further explained by the results of correlation analysis between BSIR, SCI and AFR, and the results of mediation analysis for the effect of VSIR on AFR. As discussed earlier, BSIR has positive impacts on the reduction of AFR. The results of bivariate correlation analysis (see Figure 5.14 in Section 5.3.1) show that BSIR is not significantly ($p > 0.05$) correlated with SCI ($r = 0.23$). This result indicates that the effect of basic safety investments on safety performance is direct and not mediated by safety culture. The effect of basic safety investments on safety performance is further discussed in next section (see Section 6.4).

The result of mediation analysis for the effect of VSIR on AFR (see Section 5.3.4) shows that the mediation effect of VSIR on AFR is significant. This result suggests that an increase in voluntary safety investments contributes to the cultivation of a positive safety culture, which then brings down the accident frequency rate of building projects. The positive impact of voluntary safety investments on safety culture level reflects the importance of voluntary efforts in constructing safety culture of building projects. This result supports Teo and Fang’s (2006) finding that a good safety culture is the result of a concerted effort, and requires investments in training and safe work procedures. This finding also supports Fang *et al.*'s (2006) study, which investigated the safety climate in the Hong Kong construction environment and highlighted the importance of providing enough safety resources in constructing a positive safety climate. The finding of positive relationship between safety culture level and the reduction of AFR reinforces the critical role of safety culture for improving safety performance, which has been addressed by many researchers (Fang *et al.*, 2006; Wiegmann *et al.*, 2004; Guldenmund, 2000; Cooper, 1997, 2000). For example, Cooper (1997) found that safety culture impacts not only on accident rates, but also on work methods, absenteeism, quality, productivity, commitment, loyalty and work satisfaction. Fang *et al.* (2006) argued that it is especially important for a construction company to improve its safety culture to achieve better safety performance.

Figure 6.1 describes the paths in which safety investments (TSI, BSI and VSI) impact safety performance (AFR) of building projects. It illustrates the relationships between safety investments, safety culture and safety performance. As shown in Figure 6.1, there are both direct (paths (c) and (d)) and indirect (paths (a) and (b)) effects of safety investments on safety performance. Path (c) shows the direct impact of voluntary safety investments on safety performance. Path (d) represents the direct effect of basic safety investments on safety performance. Paths (a) and (b) show the indirect impact of voluntary safety investments on safety performance. Voluntary safety investments lead to improvement of safety culture (path (a)), and then positive safety culture would bring down the accident frequency rate of projects (path (b)).

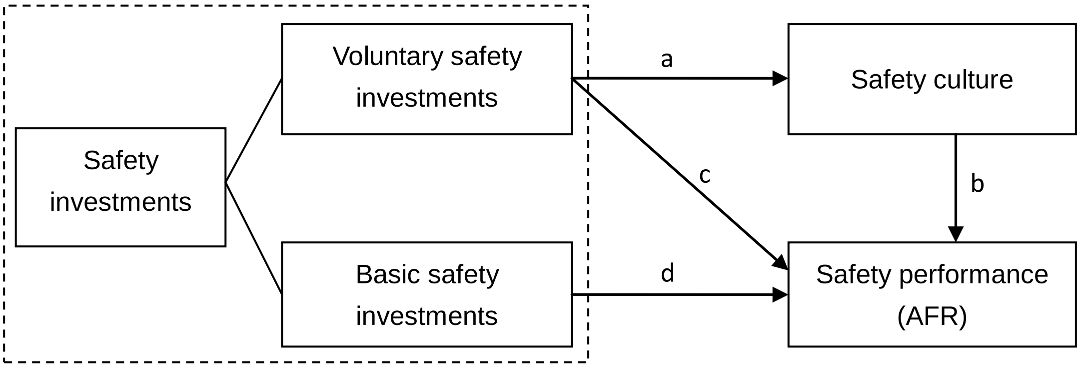


Figure 6.1: Model of the Relationships between Safety Performance, Safety Investment and Safety Culture

6.4 Basic safety investments and safety performance

Having discussed the effects of voluntary safety investments on safety performance, this section discusses the effects of basic safety investments on safety performance of building projects.

The results of bivariate correlation analysis (see Figure 5.14 in Section 5.3.1) show that basic safety investments are negatively correlated with accident frequency rate. Nevertheless, the result of moderation analysis (see Section 5.3.3) indicates that the effect of basic safety investments on accident frequency rate does not hold constant under different project conditions. The variance of the simple slopes for AFR on BSIR at different levels of PHI (see Figure 5.26 in Section 5.3.3) and SCI (see Figure 5.25 in Section 5.3.3) indicates a stronger positive effect of basic safety investments on accident prevention under higher project hazard level and higher project safety culture level. Basic safety investment plays a more critical role in accident prevention for those projects with higher project hazard level and higher project safety culture level. For those projects with lower hazard level and lower safety culture level, the role of basic safety investment is less significant in accident prevention. Noticeably, Table 5.34 (see section 5.3.3) shows that the relationship between BSIR and AFR is no longer significant when PHI is at low level (-1 Std. Dev.). Table 5.31 (see section 5.3.3) shows that this relationship becomes even positive when SCI is low (-1 Std. Dev.). It suggests that the increase in basic safety investments may lead to higher accident frequency rate if the safety culture level of the project is low. This result is inconsistent with the commonly held assumption that the higher the safety investment is, the better the safety performance will be (Hinze, 2000; Brody *et al.*, 1990; Laufer, 1987a, b; Levitt, 1975). It is also inconsistent with the findings of many empirical studies (Lanoie and Trottier, 1998; Tang *et al.*, 1997; Bertrand, 1991; Harms-Ringdhal, 1990; Spilling *et al.*, 1986), which reached the same conclusion: investments in accident prevention are profitable.

The differences between the findings of this study and the previous studies could be explained by the economic theory of risk compensation developed by Peltzman (1975) and the risk homeostasis theory developed by Wilde (1982) (please refer to Section 3.2.2 for a detailed review of the two theories).

The findings that BSIR has a stronger positive effect on accident prevention under higher project hazard level and that the effect of BSIR on accident prevention is no longer significant when the project hazard level is low may be explained by the Risk Compensation Theory developed by Peltzman (1975). Peltzman (1975) found that, under safer environment, drivers tend to increase speed rather than enjoy the increased safety associated with driving at the same speed. Peltzman's (1975) theory suggests that individuals tend to adjust their behaviour in response to perceived changes in risk. They will behave less cautiously in situations where they feel "safer" or more protected. This is seen as self-evident that individuals will tend to behave in a more cautious manner if their perception of risk or danger increases. In the construction context, basic safety investments include equipping workers with basic knowledge about occupational safety and physical protections. The increase of basic safety investment tends to enhance the workers' perceptions that the environment has become safer, especially under lower project hazard level. As predicted by Peltzman's (1975) Risk Compensation Theory, workers are likely to adjust their work behaviour in response to the perceived changes in the accident risk level. Riskier behaviours tend to result from workers' perceptions that the environment has become safer.

Risk Homeostasis Theory (Wilde, 1982) may help to explain why there is a stronger positive effect of BSIR on accident prevention under higher safety culture level and why BSI plays even a negative role in accident prevention when safety culture level is low. Risk Homeostasis Theory (Wilde, 1982) states that the degree of risk-taking behaviour and the magnitude of loss, due to accident and lifestyle-dependent disease, tend to be maintained over time unless there is a change in the target level of risk. As predicted by the risk compensation theory (Peltzman, 1975) and risk homeostasis theory (Wilde, 1982), the effect of an increase in basic safety investments is likely to be counteracted by the less cautious behaviours of workers unless there is a change in the target level of risk, which is the level of risk a person expects to accept to maximize the overall expected benefit from an activity (Wilde, 1982). Higher level of safety culture tends to be associated with higher expected safety performance and lower target level of risk (Cooper, 1997). Thus, the findings of this study implies that more protections and safer environment do not always produce better safety performance without the improvement of safety culture. This is supported by the role of safety culture in fostering workers’ safety behaviours (Uttal, 1983), increasing people's commitment to safety (Cooper, 2000), and ensuring that organisational members share the same ideas and beliefs about risks (CBI, 1991). There are occasions that individuals who take unsafe behaviours on site are conscious of the fact that these behaviours are associated with higher risk. They tend to believe that, under more safety protections and less hazardous working environment, the risks associated with their unsafe behaviour are essentially lowered. This suggests that individuals who knowingly engage in unsafe behaviours may already be cognizant of the associated risks. Such compensatory (or riskier) behaviours resulted from the perceptions that their working environment has become safer tend to be modified by a positive safety culture (Uttal, 1983). This is confirmed by the findings of many studies (Cooper, 2000; Geller, 1997; HSC, 1993; Bandura, 1986) that safety behaviours are influenced by the internal psychological factors of workers.

The moderated effect of basic safety investment on accident prevention suggests that improving safety performance from a strict engineering prospective, which emphasizes the development of safer equipment (both personal and production), is not sufficient. A good safety culture could not only increase the level of risk awareness, but also convince individuals to be less tolerant of risks. The findings of this study further reveal that the interventions that synthesize engineering advances with cultivation of a good safety culture are more likely to reduce accident rates. This is supported by the study of Cameron and Duff (2007), where they argued that engineering controls may be unable to modify disagreeable behaviours, such as wearing uncomfortable personal protective equipment (PPE). The finding of this study also supports the argument of Lingard and Rowlinson (2005) that a purely engineering approach to OHS is not likely to yield the best results. Lingard and Rowlinson (2005) further suggested that it is also important to address the psychological factors impacting upon workers' perceptions of OHS and behaviour.

6.5 Model for determining safety performance

Having discussed the effects of safety investments, safety culture and project hazard level on safety performance and the relationship between the two indicators of safety performance (AFR and ASR), this section develops the model for determining safety performance of building projects.

Based on the results of bivariate correlations between variables (see Figure 5.14 in

Section 5.3.1), the main effects of factors on safety performance are summarized in Table 6.1. Both AFR and ASR are used to measure safety performance of building projects. Table 6.1 shows that AFR is negatively and significantly ($p < 0.05$) related to safety culture level (r = -0.439), basic safety investments (r = -0.282), and voluntary safety investments (r = -0.539). ASR is significantly ($p < 0.05$) and negatively related to safety culture level (r = -0.46) and positively related with project hazard level (r = 0.363). Furthermore, Table 6.1 shows that there is a significant ($p < 0.05$) and positive relationship between the two safety performance indicators (r = 0.512).

Table 6.1: Summary of the Main Effects of Factors on Safety Performance

Dependent variable	Independent variable	Correlation of Dependent and Independent variable (r)	*N*	*Sig.*
AFR	BSIR	-0.282	47	0.045
AFR	VSIR	-0.539	47	0.000
AFR	SCI	-0.439	47	0.002
ASR	PHI	0.363	47	0.012
ASR	SCI	-0.460	47	0.001
ASR	AFR	0.512	47	0.000

The moderated effects (interactive effects) of factors on safety performance are summarized in Table 6.2. It shows that AFR is significantly affected by the interactions between basic safety investments and project hazard level, and the interactions between basic safety investments and safety culture level. ASR is significantly affected by the interactions between safety culture level and project hazard level, and the interactions between AFR and project hazard level. The result of mediated regression analysis (see Section 5.3.4) implies that safety culture level is positively related to voluntary safety investments, and that the effect of voluntary safety investments on AFR is partially mediated by safety culture level of building projects.

Table 6.2: Summary of the Interactive Effects of Factors on Safety Performance

Dependent variable	Interactive variable	Regression coefficient *B*	Adjusted R^2 of moderated regression model	R^2 contribution of Interaction term	*Sig.*
AFR	BSIR • PHI	-39.06	0.13	0.086	0.038
AFR	BSIR • SCI	-90.27	0.24	0.063	0.047
ASR	PHI • SCI	1327.83	0.38	0.056	0.046
ASR	PHI • AFR	14.68	0.346	0.044	0.043

The variables and their relationships (including the main effects, interactive effects, and mediated effects) are integrated in a graphic model for determining safety performance of building projects (see Figure 6.2).

This model demonstrates how the two safety performance indicators (AFR and ASR) are influenced by safety investments, safety culture, and project hazard level. As shown in Figure 6.2, the thin lines with double arrows represent the correlations between two variables. Path (a) shows the positive correlation between basic safety investments and voluntary safety investments. Path (b) shows the positive correlation between the two safety performance indicators (AFR and ASR).

The thin lines with single arrow represent the main effect of the independent variable on the dependent variable. Path (c) shows that AFR tends to be reduced with the increase of safety investments (including TSI, BSI, and VSI). Path (d) shows the

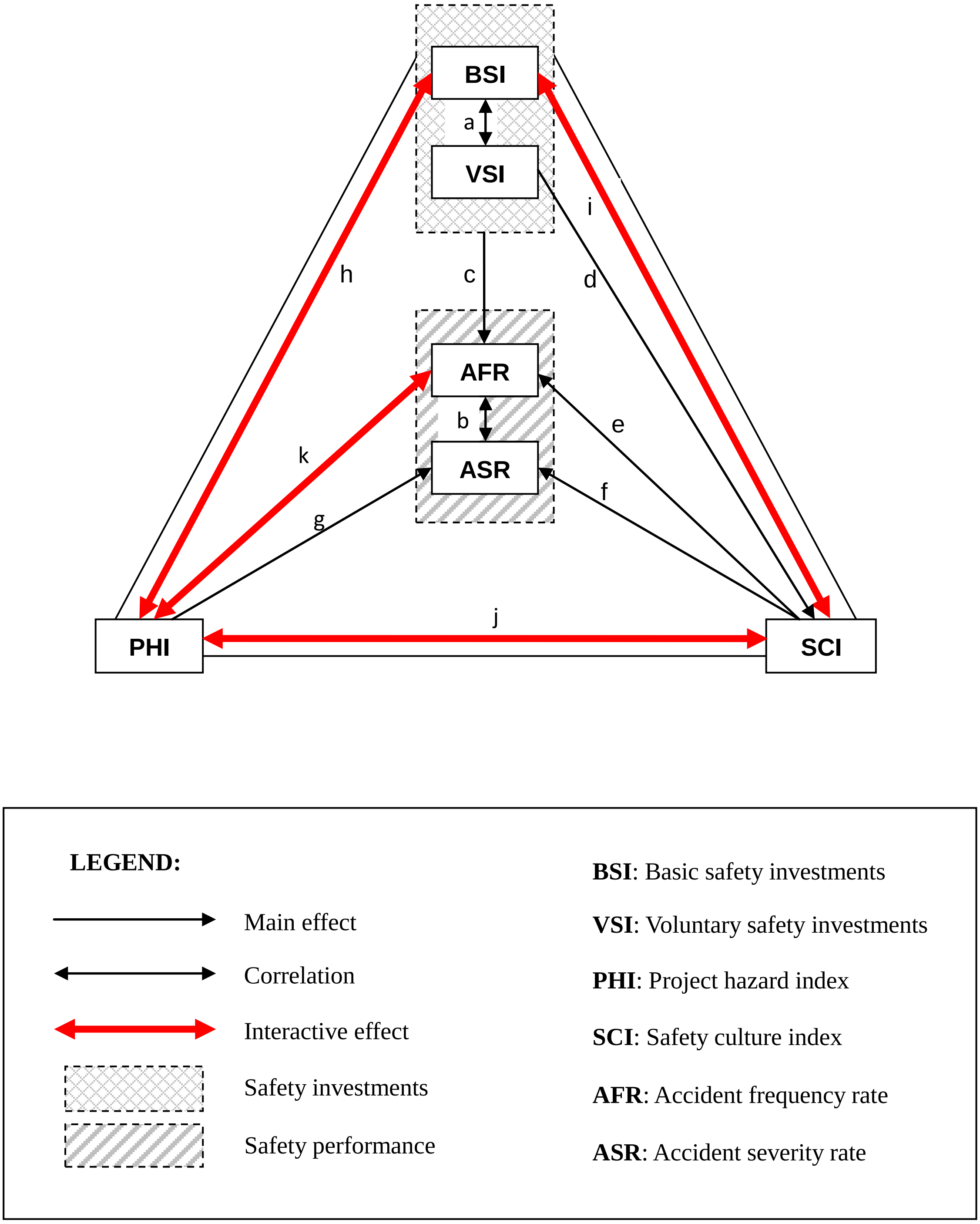


Figure 6.2: Model for Determining Safety Performance of Building Projects

positive impact of voluntary safety investments on safety culture level. Path (e) and path (f) indicate the positive effects of safety culture level on the reduction of AFR and ASR. Path (d) and path (e) demonstrate the indirect effect of voluntary safety investments on AFR. Path (g) shows the positive impact of project hazard level on ASR.

The thick lines with double arrows represent the interactive effects. As can be seen in Figure 6.2, path (h) shows the interactive effects of basic safety investments and project hazard level on AFR. Path (i) represents the interactive effects of basic safety investments and safety culture level on AFR. Path (j) reflects the interactive effects of safety culture level and project hazard level on ASR. Path (k) indicates the interactive effects of AFR and project hazard level on ASR.

This model recognizes both the main effects and interactive effects of safety investments, safety culture and project hazard level on safety performance as well as the differences between the two safety performance indicators: AFR and ASR. It indicates that safety performance of building projects is determined by the synergies of safety investments, project hazard level and safety culture level. The effect of any individual factor on safety performance is not constant but varies with the changes in other factors.

6.6 Financially optimum level of voluntary safety investments

This study aims to investigate the financially optimum level of safety investments for building projects. The methods and models for optimizing voluntary safety investments have been established in Section 5.5. The results of voluntary safety investments optimization under 9 typical scenarios are summarized in Table 6.3. It shows that the optimal level of voluntary safety investment varies with different levels of safety culture and project hazard condition. The highest level of optimal voluntary safety investment occurs with the highest project hazard level and lowest project safety culture level, while the lowest level of optimal voluntary safety investment occurs with the lowest project hazard level and highest project safety culture level.

Table 6.3: Summary of the Optimization under 9 Typical Scenarios

	-1 dev (PHI)	**mean (PHI)**	**+1 dev (PHI)**
-1 dev (SCI)	VSIR = 0.443% AFR = 15.88	VSIR = 0.459% AFR = 11.3	VSIR = 0.47% AFR = 8.97
mean (SCI)	VSIR = 0.418% AFR = 22.85	VSIR = 0.442% AFR = 16.51	VSIR = 0.46% AFR = 13.22
+1 dev (SCI)	VSIR = 0.39% AFR = 27.64	VSIR = 0.422% AFR = 20.22	VSIR = 0.445% AFR = 16.32

From Table 6.3, it can be seen that the optimal level of voluntary safety investment tends to decline with the increase of safety culture level when holding the project hazard level constant. This finding indicates that cultivating a positive safety culture would not only improve safety performance but also contribute to lower the expenditures on safety for building projects. The empirically proven critical role of safety culture in accident prevention reinforces previous studies on safety culture (e.g., Fang *et al.*, 2006; Teo and Phang, 2005; Cooper, 2000). The positive effect of safety culture to construction safety performance improvement was also confirmed in this study (see Section 6.5). However, this finding may further extend the role of safety culture in cost control of building projects. A possible reason is that, with a better safety culture, safety initiatives could be better understood by workers and management staff and thereafter more effectively implemented. This agrees with Teo and Phang (2005), who found that the proper implementation of safety initiatives is significantly affected by contractors' attitudes towards safety issues. It is also in concordant with Lingard and Rowlinson's (2005) finding that contractors may have difficulties in enforcing their safety programmes on workers who do not understand these programmes. Another possibility is that the efficiency of safety initiatives would be undermined if contractors attached too much emphasis on productivity. This is evidenced by the studies of Goldenhar *et al.* (2003) and Ahmed *et al.* (1999), where they found that tight construction schedules caused problems in implementing safety programs. The marginal returns of the investments in safety and the effects of safety interventions appear to be more significant for those organisations in which everybody has a positive attitude towards safety and is committed to build a safer work environment. Thus, the finding of this study would give another impetus (i.e., to lower the expenditures on safety) for contractors to promote safety culture in their projects.

Table 6.3 also shows that the optimal level of voluntary safety investment is higher for projects with higher project hazard level when holding the level of safety culture constant. This is mainly because of the role of project hazard level in determining total accident costs of building projects. Based on the analysis in Section 5.4, the total accident costs tend to be higher with the increase of project hazard level and the effect of accident frequency rate on total accident costs tends to be stronger under higher project hazard level. Therefore, when the project hazard level is higher, contractors have to take more efforts to lower the accident frequency rate so that the lowest level of total controllable safety costs could be achieved.

Moreover, Table 6.3 shows that higher VSIR corresponds to lower AFR. More interestingly, it is found that small changes in VSIR tend to bring about more significant changes in AFR. This finding implies that the improvement of safety performance is sensitive to the changes in the levels of voluntary safety investments. This finding further supports the earlier finding that the effect of voluntary safety investments on accident prevention is more significant than that of the basic safety investments (see Section 6.3.1).

Table 6.3 shows that the optimal level of voluntary safety investment of building projects in Singapore was found to be about 0.44% (i.e., when both SCI and PHI are at the mean level) of the contract sum. Based on the principle of optimum safety costs, it would initially seem that a voluntary safety investment of more than the optimal figure indicated in this study will increase the total controllable safety costs and thus is unnecessary. However, this figure should be regarded as a minimum amount of voluntary safety investment in a building project. The reasons are discussed below.

Figure 6.3 describes the schematic relationships between VSIR, TACR, TCCR and AFR based on the results of Section 5.5. The VSIR curve is derived from Eq. 5.21. The TACR curve is derived from Eq. 5.28. The VSIR curve has a negative slope since, as the VSIR is increased, the AFR declines; whilst the TACR curve has a positive slope since the total accident costs vary positively with the accident frequency rate. The TCCR curve is derived from Eq. 5.29. It is the vertical sum of the VSIR curve and TACR curve. Theoretically, there is a minimal point on the TCCR curve. As shown in Figure 6.3, the point “M” minimizes total controllable safety costs with y_1 as total accident costs ratio and y_2 in voluntary safety investments ratio at the accident frequency rate of x. Thus, from the financial perspective, y_2 represents the optimal level of voluntary safety investments since it coincides with the minimal level of total controllable safety costs.

As can be seen in Figure 6.3, an investment exactly at the optimal level (y_2) would result in the best financial performance (the minimal point of TCCR curve) and a fairly good safety performance. If contractors chose a level of voluntary safety investment less than the optimal level (y_2), they would probably suffer both financial losses and poorer safety performance. The contractors would also suffer higher financial costs if they chose a level of voluntary safety investment greater than the optimal level (y_2), nevertheless, a better safety performance would be achieved.

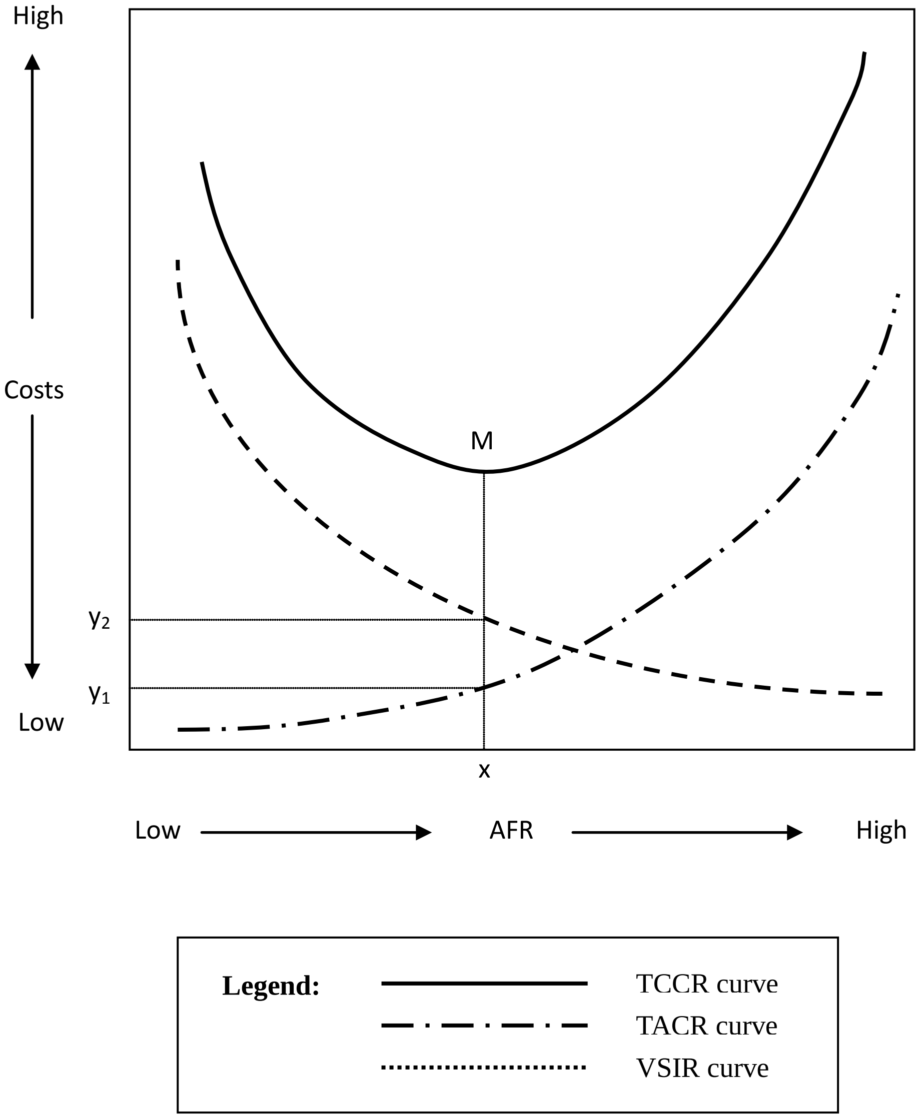


Figure 6.3: Schematic Relationships between VSIR, TACR, TCCR and AFR

Thus, “y_2” in Figure 6.3 would only represent the financially optimal level of voluntary safety investment of building projects and should be regarded as the minimum level of voluntary safety investment to achieve the overall balance of financial performance and safety performance. It is because the potential benefits of better safety performance may outweigh the possible increase of financial costs that resulted from a voluntary safety investment greater than the optimal level “y_2”. This is supported by many researchers (e.g., Mohamed, 2002; Hinze, 1997; Tang *et al.*, 1997; Grimaldi and Simonds, 1975), who found that better safety performance may result in intangible benefits, such as greater job satisfaction of employees, better reputation of the company, better relationship with the project owner, stronger corporate competitiveness and so on, which are valuable assets to the contractors. Lingard and Rowlinson (2005) further suggested that such benefits are likely to be underestimated because many of them are intangible and difficult to measure. This is also consistent with Hopkins's (1995) finding that, without knowing the magnitude of the intangible benefits as a result of safety performance improvement, it is not likely to reduce risk to a level reflecting the true optimum point.

Thus, this study does not suggest that no further investments are needed once the financially optimum point is reached. This is because it is not clear whether the corresponding accident frequency rate is tolerable for individual companies (Lingard and Rowlinson, 2005; HSE, 1993b). More voluntary safety investments beyond the financially optimum level may be necessary to reduce the accident rates to a tolerable level, which may reflect the corporate value system and the moral and ethical considerations (Lingard and Rowlinson, 2005). It is therefore suggested that the desirable level of voluntary safety investments should be determined by not only the financially optimum level of voluntary safety investments but also the tolerable levels of accident rate.

Although the above discussions suggest that the financially optimal level of voluntary safety investments does not reflect the desirable level of voluntary safety investments, the finding of the financially optimal VSIR is still of value because it defines the minimal requirement about the level of voluntary safety investments in building projects. The financially optimal level of voluntary safety investments refers to a certain amount of voluntary safety investments which coincide with the minimal point of total controllable safety costs. An investment below the financially optimal level would result in not only poorer financial performance but also poorer safety performance. This may serve as an impetus for the contractors to voluntarily take up investments in accident prevention. The financially optimal level of voluntary safety investments may also provide a basis to support the decision making on the level of safety investments for building projects. It is hoped that the current research will inspire further developments of desirable level of safety investments in future studies (please refer to Section 7.8 for more details)

6.7 Summary

In this chapter, the empirical results from the data analysis were discussed in the context of theories. The discussions mainly concerned the effects of safety investments on safety performance of building projects, the model for determining safety performance of building projects, and the financially optimum level of voluntary safety investments in building projects. These findings have many implications to theories and practices. The next chapter will conclude this study and discuss the contributions to knowledge and practices, limitations and recommendations.

CHAPTER SEVEN

CONCLUSIONS

CHAPTER 7: CONCLUSIONS

7.1 Introduction

Based on the data analysis and discussions of results in Chapter 5 and Chapter 6, the conclusions of this study are presented in this chapter. A brief summary of this study is described in Section 7.2. The key findings addressing the research aim and objectives are summarized in Section 7.3. Then, the implications of the findings for theory and practice are discussed in Sections 7.4 and 7.5. Section 7.6 presents some recommendations for safety management practices in construction sites. Finally, the research limitations and suggestions for future research are discussed in Section 7.7 and Section 7.8.

7.2 Summary

The construction industry is increasingly reliant on the voluntary and self-generating effort to reduce accidents on construction site. As the investments in construction safety cannot be limitless, there is a need for a scientific way to support the decision making about the investments in construction safety. This need was addressed in this study by investigating the financially optimum level of investments in workplace safety for building projects in Singapore.

Four specific objectives were defined within the context of building construction at the level of contractor project organisation in Singapore (see Chapter 1). To fulfill these objectives, a theoretical framework (see Chapter 3) for the interrelationship between safety investments, safety culture, project hazard level, safety performance and accident costs was developed based on the literature review (see Chapter 2). The positivistic paradigm and quantitative approach were adopted to achieve the research aims. A correlation/regression research design was adopted by this study. Data were collected using multiple techniques comprising structured interviews, review of archival data and questionnaires (see Chapter 4). Data collected were analyzed using various statistical and mathematical techniques, e.g., bivariate correlation analysis, regression analysis, moderation analysis, mediation analysis and extreme value theorem (see Chapter 5). The empirical results of the data analysis were then discussed in the context of theories (see Chapter 6). The next section summarizes the key findings and evaluates the achievement of the research objectives.

7.3 Key findings

As stated in Chapter 1, this study aims to investigate the financially optimum level of investments in workplace safety through exploring the relationships between safety investments, safety performance and accident costs for building projects in Singapore. This aim is particularized into four specific research objectives. The key findings of this study addressing the research aim and objectives are summarized in the following sections.

7.3.1 Effects of safety investments on safety performance of building projects

The first objective of this study is to examine the effects of safety investments on safety performance of building projects. This objective has been achieved by way of testing Hypotheses 1.1, 1.4 and 1.5 of the first group of hypotheses, which are summarized in Table 7.1. Safety performance of building projects can be improved with the increase of overall level of safety investments. However, different types of safety investments have different effects on safety performance. Voluntary safety investments are more effective to reduce accident frequency rate of building projects than basic safety investments. The effect of basic safety investments on accident prevention varies with different levels of safety culture and project hazard. There is a stronger positive effect of basic safety investments on accident prevention under higher project hazard level and higher project safety culture level. Increase in voluntary safety investments contributes to the cultivation of a positive safety culture, which then brings down the accident frequency rate of building projects.

Table 7.1: Results of Hypotheses Testing (Hypothesis 1)

Item No.	Hypothesis Description	Supported or Not
1.1	Safety performance of building projects varies positively with the level of safety investments.	Yes*
1.2	Safety performance of building projects varies positively with the level of safety culture.	Yes*
1.3	Safety performance of building projects varies inversely with the project hazard level.	Yes*
1.4	The effect of safety investments on safety performance varies with the project hazard level.	Yes*
1.5	The effect of safety investments on safety performance varies positively with the level of safety culture.	Yes*

* $p < 0.05$

7.3.2 Model for determining safety performance of building projects

The second objective of this study is to develop a model for determining safety performance of building projects. This objective has also been achieved by testing the first group of hypotheses (see Table 7.1). The first main hypothesis (i.e. safety performance of building projects is determined by the level of safety investments, safety culture level and project hazard level as well as the interactions among the three variables) is confirmed, as a result of substantiation of the sub-hypotheses. Moreover, the relationship between accident frequency rate and accident severity rate becomes stronger when the project hazard level is higher. Thus, a model was constructed to demonstrate how the two safety performance indicators are influenced by safety investments, safety culture and project hazard level. This model shows that safety performance of building projects is determined by the synergies of safety investments, project hazard level and safety culture level. The effect of any individual factor on safety performance is not constant but varies with the change of other factors.

7.3.3 Costs of accidents for building projects

The third objective of this study is to investigate the costs of accidents to building contractors. This objective has been achieved by testing the second group of hypotheses, which are summarized in Table 7.2. The average direct accident costs, indirect accident costs and total accident costs of building projects account for 0.165%, 0.086% and 0.25% of contract sum, respectively. The total accident costs of building projects are influenced by both accident frequency rate and project hazard level. The relationship between the number of accidents and the costs of accidents is dependent on the project hazard level. There is a stronger positive effect of accident frequency rate on total accident costs under higher project hazard level.

Table 7.2: Results of Hypotheses Testing (Hypothesis 2)

Item No.	Hypothesis Description	Supported or Not
2.1	The total accident costs of a building project vary positively with the accident frequency rate.	Yes*
2.2	The total accident costs of a building project vary positively with the project hazard level.	Yes*
2.3	The total accident costs of a building project vary with the project characteristics.	No*
2.4	The effect of accident frequency rate on the total accident costs of a building project varies with the project hazard level.	Yes*

* $p < 0.05$

7.3.4 Optimization of safety investments

The last objective is to study the optimization of safety investments for building projects. To achieve this objective, the model for predicting total controllable safety costs ratio was constructed through the combination of voluntary safety investments ratio curve and total accident costs ratio curve, which were developed using regression methods. The optimisation of voluntary safety investments ratio was conducted using the extreme value theorem and with the objective of finding the minimal level of total controllable safety costs. It was found that the financially optimum level of voluntary safety investments varies with different levels of safety culture and project hazard. It is a function of project hazard level and safety culture level. The financially optimum level of voluntary safety investments of building projects in Singapore is about 0.44% of the contract sum (i.e., when both safety culture and project hazard are at the mean level). Thus, the fourth objective of this study (i.e., to study the optimization of safety investments for building projects) has been achieved.

7.4 Contribution to knowledge

This study contributes to knowledge in construction safety management by investigating the desirable level of safety investments for building projects. It offers a better understanding of the theory behind: (1) the relationship between safety investments and safety performance; (2) the interrelationship among the variables determining safety performance of building projects; (3) the costs of accidents for building projects; and (4) the optimization of safety investments for building projects.

Firstly, this study contributes to the theory behind the relationship between safety investments and safety performance of building projects. A popular assumption about the relationship between safety investments and safety performance holds that the higher the safety investments are, the better the safety performance will be (e.g., levitt, 1975; Brody *et al.*, 1990; Hinze, 2000). This study confirmed the general positive relationship between total safety investments and safety performance of building projects. By examining the effects of different types of safety investments (i.e., basic safety investments and voluntary safety investments) on safety performance, this study adds some new insights into the relationship between safety investments and safety performance of building projects:

- voluntary safety investments are more effective or efficient for accident prevention than basic safety investments;

- the effect of basic safety investments on accident prevention is moderated by safety culture and project hazard level of building projects;
- basic safety investments have a stronger positive effect on accident prevention under higher safety culture level and project hazard level;
- the effect of basic safety investments on accident prevention might not be positive if project hazard level and safety culture level of the project were low; and
- the effect of voluntary safety investments on accident prevention is partially mediated by safety culture of building projects.

Secondly, this study developed a model for determining safety performance of building projects. The accident causation theories developed by many researchers (e.g., Heinrich, 1931; Peterson, 1971; Bird, 1974; Abdelhamid and Everett, 2000) suggest that safety performance of building projects is associated with the inherent hazard level in the project and the level of human efforts in accidents prevention. The model developed in this study (see Figure 5.6 in Section 5.9) confirmed that safety performance of building projects is influenced by safety investments, safety culture and project hazard level. The possible innovations of this model lie in the following aspects:

- this model recognizes the interactive effects of safety investments, safety culture and project hazard level on safety performance;

- this model recognizes the differences of the two safety performance indicators: accident frequency rate and accident severity rate; and
- this model recognizes both the direct and indirect effects of safety investments on safety performance.

Next, this study examined the costs of accidents for building projects. It appears to be the first known research to estimate the costs of accidents to Singapore’s building contractors. It was found that the average direct accident costs, indirect accident costs and total accident costs of building projects in Singapore account for 0.165%, 0.086% and 0.25% of total contract sum, respectively. This study adds to the theory of accident costs (Hinze, 1991; Bird, 1974; Simonds and Grimaldi, 1963; Heinrich, 1931) in that the relationship between total accident costs and accident frequency rate of building projects is moderated by project hazard level. There is a stronger positive relationship between total accident costs and accident frequency rate of building projects under higher project hazard level.

Finally, this study contributes to the theory behind the optimization of safety costs and investments. The principle of optimum safety costs states that a company would invest a certain amount of dollars in safety which coincide with the minimal point of total safety costs (e.g., Hinze, 2000; HSE, 1993b; Diehl and Ayoub, 1980; Tang *et al.*, 1997). This study provides empirical evidence to support the principle of optimum safety costs. It demonstrates that the financially optimum level of voluntary safety investments could be achieved through the minimization of total controllable safety costs of building projects (see Section 7.4). Moreover, this study improves the safety costs optimization model (Tang *et al.*, 1997) by integrating the impacts of project hazard level and safety culture level of building projects in the analysis. It was found that the financially optimum level of voluntary safety investments is affected by project hazard level and safety culture level of building projects. This improvement enables that the financially optimum VSIR formula (presented as the function of PHI and SCI) could be tailored for an individual building project.

7.5 Contribution to practice

The findings of this study provide the basis for financial decision making to manage construction safety for building contractors. The findings suggest that the efficiency or effectiveness of safety investments is dependent on the project hazard level and safety culture level of building projects. Such knowledge implies that the improvement of safety performance relies on the synergies of two kinds of human efforts, i.e., safety investments and safety culture. By applying the findings of this study, contractors may achieve safety performance improvement with reasonable expenditure on accident prevention activities.

The models and procedures for safety costs optimization can be used in various stages of a building project. In the project tendering stage, the proposed models and procedures are able to propose to contractors a budget for safety related activities. It can also be used by the clients as a basis to assess the reasonableness of the safety management components of the tendering price offered by contractors.

In the construction stage, the proposed models and procedures for deriving financially optimum level of voluntary safety investments should be of interest to building contractors as they may use it to check the adequacy of the resources allocated to safety control activities based on the suggested minimal level of voluntary safety investment. It may help to effectively allocate resources to various activities within the fixed project budget and to better control the costs of the whole project.

7.6 Recommendations

Based on the findings of this study, some recommendations for safety management practices are now presented.

- The finding of the moderated effect of basic safety investments on accident prevention (refer to Section 6.4 for detailed discussion) implies that more protections and safer environment do not always produce better safety performance without the improvement of safety culture. The interventions which emphasize the provision of physical protections (both personal and production) and the enforcement of formal safety training courses are not sufficient. It is also important to address the cultural factors impacting upon workers’ perceptions of safety and behaviours. It is recommended for contractors to implement the interventions that synthesize engineering advances with cultivation of a good safety culture.

- The finding of the stronger positive effect of basic safety investments on accident prevention under higher project hazard level (refer to Section 6.4 for detailed discussion) implies that different investment decisions in workplace safety need to be made under different project conditions. As recommended by Feng and Teo (2009) and Teo and Feng (2010), to achieve a certain level of safety performance, more basic safety investments (e.g., provision of PPEs and safety facilities, and enforcement of formal safety training courses, etc.) are required for those projects with higher project hazard level than those with lower project hazard level.

- The finding of the direct and indirect effects of voluntary safety investments on accident prevention (see Section 6.3 for detailed discussions) suggests that voluntary safety investments are important for accident prevention as they may not only reduce the accident frequency rate but also promote a good safety culture on site. Previous studies also suggest that safety inspections and investigations (Aksorn and Hadikusumo, 2008; Poon *et al.*, 2000; Jaselskis *et al.*, 1996; Tam and Fung, 1998), safety committees and meetings (Tam and Fung, 1998; Jaselskis *et al.*, 1996), safety promotions and incentives (Aksorn and Hadikusumo, 2008; Tam and Fung, 1998; Jaselskis *et al.*, 1996), and in-house safety trainings and orientations (Findley *et al.*, 2004; Tam and Fung, 1998) were among the most effective safety measures for construction safety performance improvement. Thus, based on the definition of voluntary safety investments (refer to Section 4.3.1), the investments (including dollars and time spent on the accident prevention activities) in the following activities deserve sufficient considerations: (1) in-house safety training; (2) safety inspections and meetings; (3) safety incentives and promotions; and (4) safety innovation (please refer to Section 4.3.1 for details).

- The analysis of accident costs of building projects (see Section 5.4 for detailed discussions) implies that the indirect accident costs are substantial for building projects and should be paid much attention to, especially for those projects with more work completed by subcontractors and in larger companies (see Section 5.4.2). The existence and magnitude of the indirect accident costs would stimulate additional accident prevention expenditures. Thus, the focus on the perceived or explicit costs of accidents fails to show the "true reality" of accident costs. It is recommended that contractors may use the Section D of the questionnaire of this study (see Appendix) to estimate the direct and indirect accident costs for their building projects.

- As mentioned in Section 7.5, the models and procedures for safety investments optimization can be used in the project tendering stage to propose to contractors a budget for safety related activities. As it is not possible to estimate the AFR, PHI and SCI based on the actual information in this stage, it is recommended that the contractors may use the estimated target AFR based on the company/project targets, corporate/project strategies, and firm’s past safety records. The attributes of various hazard trades could be assessed based on the design documents, site conditions, technical proposals, and past experiences in similar projects. In addition, the SCI could be estimated through the review of the safety management systems in the company and the assessment of safety culture in other ongoing projects carried out by the contractor.

- The findings of this study also have implications for clients of building projects. As safety investments have a general positive impact on safety performance (refer to Section 5.3), clients of building projects are suggested to support the contractors’ investments in accident prevention activities by setting up a separate budget for safety. It is also suggested that clients may use the models and procedures for safety costs optimization to evaluate the reasonableness of the safety budget proposed by contractors. Moreover, considering the critical role of safety culture in accident prevention (refer to Sections 6.3 and 6.4 for more discussions), clients of building projects are recommended to include the assessment of safety culture of contractors as a selection criterion.

7.7 Limitations of study

The limitations of this study are now discussed.

The first limitation is that the costs of workplace accident are confined to the financial losses of a contractor. Other ancillary costs arising from the accident, such as damage to company reputation and morale of employees were not included in this study. This is because the ancillary costs are intangible and difficult to quantify. Another limitation lies in the theoretical basis of safety costs optimization. The optimization was based on the economic principle of profit maximization. However, profit maximization may not be the primary business target for many companies, especially for public or state-owned companies. Thus, the financially optimum solution may not be the sole criteria for decision making on WSH. Other criteria like the tolerable risk level should be considered when making decisions. However, these two limitations did not impact the validity of the results of this study as this study suggested (see Section 7.5) that the financially optimum level of voluntary safety investments should be regarded as the minimum level of voluntary safety investments. Despite this, it is acknowledged that a more rigorous model could be proposed to quantify the optimal level of voluntary safety investments of building projects if the intangible accident costs and the tolerable risk level of individual companies were considered. This leads to future research possibilities discussed in the next section.

The third limitation of this study lies in the choice of research approaches. The findings of this study were reached based on the use of a correlation/regression research design. It is effective in testing the associations between variables, but not effective in explaining the causal mechanism among variables. It is acknowledged that the explanation of the relationship among variables would be more incisive if qualitative data (e.g., observation and in-depth interview) were collected. This limitation leads to future research possibilities discussed in the next section.

The fourth limitation is that the response rate and the sample size were not as large. The data was obtained from 47 building projects of 23 building contractors, representing a response rate of 20%. The relatively lower response rate may impact the representativeness of the contractors selected. However, this impact was minimized by the stratified sampling method and the random selection process (see Section 4.3). Moreover, the analysis shows that the relatively small sample size (n=47) did not affect the validity of the results as the effect size and statistical power of the analysis were satisfactory.

The fifth limitation lies in the accuracy/reliability of the data collected. Regardless of the field of study or preference for defining data (quantitative, qualitative), accurate data collection is essential to maintaining the integrity of research. Inaccurate data may distort the fact and lead to misleading inferences. It is acknowledged that it is not likely to collect absolutely accurate data, not only because a research instrument cannot be so but also because it is impossible to control all the factors affecting reliability (Kumar, 2005). However, to minimize the threat of inaccuracy of data collected to the validity of the findings, two strategies were adopted by this study: (1) adopting a proactive attitude towards this issue and carrying out precautions to mitigate the threat of this issue (please refer to 4.3.7.2 for details of precautions); and (2) interpreting the statistical results in the context of the theory and of results of previous research.

The sixth limitation concerns the use of indexes (PHI and SCI) to measure the levels of project hazard and safety culture. It is acknowledged that it is not likely to have an absolute measure of safety culture and project hazard. The PHI and SCI can only provide relative measures of project hazard level and safety culture level. This limitation may result in the incorrect specifications of the regression models and incorrect relationships between variables. To minimise the potential threats of this limitation to the validity of the findings, this study adopted the following strategies: (1) establishing the validity and reliability of the data collection instrument (refer to Section 4.3.7.1 for details); (2) proactively identifying potential threats of bias and carrying out precautions to mitigate them (refer to Section 4.3.7.2 for details); and (3) interpreting the statistical inferences in the context of theories and literature.

The last limitation lies in the generalizability of the findings. The findings were reached based on the information of 47 building projects in Singapore. Thus, findings of this study should be interpreted in the context of building construction in Singapore. The profile of the projects (see Section 4.5.2) shows that the data were collected from a wide range of building projects but with a focus on residential (63.8%), medium-size (83%), and private-sector building projects (83%). The findings are based on this set of data and hence generalizations to other populations may be difficult.

7.8 Recommendations for future study

As highlighted in Section 7.7, several areas of interest can be further explored in future studies. These areas are now discussed.

As highlighted in the first limitation (see Section 7.7), the costs of workplace accident are confined to the financial losses of a contractor in this study. In a future study, a method for quantifying the intangible costs to contractors incurred by accidents could be developed. The intangible accident costs may serve as a better motivation for contractors to voluntarily invest in accident prevention activities. A more rigorous model could be proposed to quantify the optimum level of safety investments for building projects with consideration of the intangible accident costs.

The second limitation mentioned that the financially optimum solution may not be the sole criteria for decision making on WSH. Other criteria like the tolerable risk level should be considered when making decisions. The tolerable risk level tends to be associated with the corporate culture and management targets of individual companies. Thus, in a future study, a more rigorous decision making mechanism on the desirable level of safety investments could be developed with consideration of tolerable risk level and management targets of individual companies.

As mentioned in the third limitation, quantitative data are effective in testing the associations between variables, but not effective in explaining the causal mechanism among variables. Future studies may be carried out using both quantitative and qualitative data. For example, case studies and in-depth interviews could be used to illustrate the reasons why safety investments have a stronger positive impact on safety performance under high project hazard conditions. Observational research techniques may be employed to investigate how the risk compensation behaviours may occur when the workers are provided with more physical protections. The validity of the relationship among the variables may also be boosted by collecting both quantitative and qualitative data.

As suggested in the last limitation, the data comprised a mixture of residential buildings (63.8%) and other building types. In future, a study may be conducted to examine whether the amount of safety investments varies with different types of buildings. More sets of data should also be collected so that separate models may be developed for different types of buildings.

Another area of interest that can be further explored is to develop a Decision Support System (DSS) for safety investments of building projects based on the findings of this study. A decision support system has been described as an interactive computer-based system which may help decision makers to use data and models to solve unstructured problems (Gorry and Scott Morton, 1971). The DSS for safety investments could be developed using MATLAB, VBA^{TM} and MS Access^{TM} software with the aid of computer specialists.

Finally, the topic of safety costs and investments may also be investigated using the marginal analysis approach. In a future study, the allocation of resources to health and safety can be examined based on the principle that the marginal cost of control measures should be no more than the marginal cost of the injury or ill-health. The major problems involved in the application of the marginal analysis approach lie in the following aspects: (1) the difficulties in identifying and quantifying the benefits of health and safety; (2) the allocation of the benefits (it is possible that a range of stakeholders who bear none of the costs receive the benefits); and (3) the valuation of human health effects and human life. These aspects deserve further exploration in future research.

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APPENDIX

QUESTIONNAIRE

National University of Singapore, Department of Building

INTERVIEW ON SAFETY INVESTMENTS/COSTS OF BUILDING PROJECTS IN SINGAPORE

Dear Sir/Madam

We are conducting a study to investigate the desirable level of safety investments in building projects of Singapore. In this regard, your help is needed by providing us with information on the workplace safety practices of one of your building projects that were completed within the past three years in Singapore. The information sought include characteristics of your project, safety control activities of your project and accident costs.

There are no commercial interests involved in this study. All information we obtain will be treated with strict confidentiality and used solely for the purpose of research. This research is supervised by Dr Evelyn Teo, Assoc Prof Florence Ling and Prof Low Sui Pheng.

I would be very grateful if you could grant me an interview at a place and time that is convenient to you. The interview is likely to last one to two hours. I look forward to your reply and thank you in advance for your help.

Yours faithfully

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SAFETY INVESTMENTS/COSTS OF BUILDING PROJECTS IN SINGAPORE

Please answer the questions based on a building project completed within the last three years.

Section A: Project and Contractor Information

1. Project name(Optional):____
2. Company name(Optional):____
3. BCA Grade of your company (please circle): A1; A2; B1; B2; C1; C2; C3.
4. Contract sum: S$_________________________
5. Duration of the project:__________________months.
6. Year of completion:________________________
7. How many contractors (main and sub contractors) are there on this project? Include your own company in this total: ________________contractors.
8. Percentage of work completed by subcontractors (in terms of contract value):____________%
9. Total man-days worked inclusive of subcontractors (till completion) :____________________
10. Height of building:_____________________Stories
11. Type of the project: [ ] Commercial building; [ ] Residential building;
    [ ] Office building; [ ] Industrial building;
    [ ] Others, please specify________________________________
12. Proportion of foreign workers:_____________________%
13. Type of client: [ ] Public; [ ] Private

Section B: Safety Performance

14. **Total number of injured workers: __________**
    - Number of fatal deceased workers:_____________
    - Number of injured workers who are permanently disabled:_____________
    - Number of injured workers who are temporarily disabled (more than 3 days of medical care):______________
    - Number of minor injuries (i.e., three or less days lost):________________
15. **Number of man-days lost due to accidents:_________________**

Section C: Investments in Safety Control Activities of the Project

16. Staffing costs

Post	Type (Part-time or Full-time) & Number	Monthly Wages (S$)	Percentage of Time Spent on Safety Work
On-site module			
Safety manager			
Safety officer			
Safety supervisor			
Lifting supervisor			
Admin support to safety personnel			
Others			
Head office module (Please fill in monthly wages on pro rata according to number of projects supervised in the same period)			
Director (safety)			
Safety manager			
Safety officer			
Safety coordinator			
Admin support to safety personnel			
Others			

17. Training costs

17.1 Costs of formal training courses (including subcontractors)

	Training courses	Costs (S$)	Total No. of participants	Duration for each time (Hours)
1	Safety training courses for project managers			
2	Safety training courses for foremen and supervisors			
3	Safety training courses for workers			
4	Safety training courses for operators/signalmen			
Total costs of formal safety training courses			---------------	-----------------------

17.2 In-house safety training and orientation for workers (including sub-contractors)

	Safety training and orientation	**Total No. of participants**	**Average hourly wages of the participants**	**Duration of each time**	**Frequency**
1	Safety orientation before work commences each day				
2	Emergency response and drills for various possible situations				
3	Briefing on first-aid facilities, first aiders, and first aid procedures				
4	Briefing on major hazards on site (including health hazards like noise & air contaminants)				
5	Safety workshops for supervisors and above				
6	Safety seminars and exhibitions, demonstration of safe work procedures and first-aid drills				
7	Other in-house training activities				

18. Total safety equipments/facilities costs

Item	**Costs (S$)**
Personal Protective Equipments	
Safety facilities (material costs)	
Safety facilities (manpower costs)	
Other costs	
Total costs	

19. Safety committees

19.1 Is there a site safety committee?

[ ] Yes (if so, please go to Q21.2); [ ] No (if so, please go to Q22).

19.2 The budget allocated for the activities of the safety committee is: S$__________________

19.3 The number of committee members is:______________________________

19.4 Please estimate the average attendance rate and average duration of the activities conducted by safety committee (exclusive of time spent on site environmental control activities)

Activities	**Attendance rate (%)**	**Average hourly wages of the participants**	**Duration (Hours)**	**Times or frequency**
Committee meetings				
Inspections on a regular basis				
Special inspections (e.g. occurrence of near misses)				

20. Safety promotion costs (exclusive of those spent on site environmental control purpose)

Activities	**Costs (S$)**
Safety boards, banners and posters at prominent locations on site	
Safety pamphlets about safety policies, promotional materials and safety rules and regulations	
Others	

21. Safety incentives

- Costs of safety incentive/award: S$________________________________

22. Safety inspections (exclusive of those for site environmental control purpose)

Type of inspection	Frequency	Duration (hours)	Number of workers who had to stop their work due to the inspection?	Average hourly wages of the workers (S$/hour)
MOM safety inspection				
Safety audit				
Head office safety inspection				
Internal safety inspections				

23. Use of new technologies, methods, and tools for the sake of workplace safety.

- Increased production costs incurred by the use of new technologies, methods and tools: S$____________________(or ________________man-days)

Section D: Accident Costs

24. The amount of Work Injury Compensation Insurance premiums paid for this project:

S$__________________________

25. Please estimate the average costs of the minor injuries (i.e., three or less man-days lost):

S$______________________

The rest of the questions in this section are designed for the filling of ONE reportable accident (including fatal, permanently disabled and temporarily disabled injuries). **For more than one accident, please photocopy this section for other accidents**. Please provide the information based on a job related accident that happened in the project.

26. Information about injured workers

26.1 Craft/occupation: __________________________________

26.2 Nature/severity of injury (please tick the box)

[ ] Death;

[ ] Permanent Incapability;

[ ] Temporarily Incapability, days of medical leave:___________days

[ ] Minor cases, days of medical leave:__________days

26.3 Job relatedness of injury (please tick the box)

[ ] Injury is clearly related to work activities;

[ ] Injury not verified as being work related, but worker claims it is or is covered by worker’s compensation.

26.4 Hourly wages of injured worker: S$__________________/hour

27. Compensation for the injured worker paid by project

27.1 Medical leave wages that are not covered by insurance policy:

___________Days × ___________S$/day = S$ ____________

27.2 Medical expenses that are not covered by insurance policy: S$_____________________

27.3 Lump sum compensation for Permanent Incapacity (PI) or death that are not covered by insurance policy: S$_________________________

28. Lost productivity due to the injured worker

28.1 Number of productive hours lost by injured worker on the day of injury:__________hours

28.2 Number of productive hours lost by injured worker due to follow-up medical treatment: _______________hours

28.3 Assuming the injured worker’s productivity was 100% before the injury, what was his productivity after returning to work? _______________________%

28.4 How many hours did the injured worker work at this reduced level of productivity?

___________________Hours **OR** _______________man-days.

29. Lost productivity due to crew of injured worker

29.1 Number of hours fellow workers spent assisting the injured worker in obtaining medical treatment (e.g., getting first-aid, transportation, accompaniment to treatment facility, etc.): ____________________hours.

29.2 Average hourly wage of these assisting workers: S$_____________/hour

29.3 Was the crew productivity decreased because of the worker’s injury or absence?

[ ] Yes; [ ] No, please go to Q30.

29.4 If the answer of the above question (Q29.3) is “Yes”, please answer the following three questions:

(a) Crew productivity after the injury was _____% of the productivity before the injury;

(b) How many hours did the fellow workers work at this reduced level of productivity? _________________hours;

(c) Average hourly cost of crew: S$_____________/hour

30. Lost productivity due to other workers in vicinity of accidents

30.1 Were any other workers near the accident site non-productive due to time spent watching or talking about it?

[ ] No;

[ ] Yes, the number of non-productive hours were _____________at an average hourly cost of S$_____________/hour (i.e. the average hourly wage of the workers)

31. Losses due to replacement of the injured worker

31.1 Was another worker hired to replace the injured worker?

[ ] No, please answer Q32; [ ] Yes, please answer Q31.2.

31.2 Please answer the following four questions:

(a) The replacement worker’s productivity was __________% of the injured worker’s prior to the injury;

(b) The replacement worker worked ______________hours at this level of productivity;

(c) The replacement worker’s hourly wage was S$_______________/hour;

(d) The costs incurred by the recruitment, selection, training and certification of new workers to replace the injured worker (e.g., costs of Man-year): S$_______________

32. Did the investigation or inspection as a result of this injury adversely impact the productivity of any work crews?

[ ] No; [ ] Yes, it is estimated that the inspection/investigation resulted in hours of lost productivity at an average cost of S$___________/hour.

33. Cost of supervisory/staff effort

33.1 Time spent assisting the injured worker: ____________hours at average costs of S$__________/hour

33.2 Time spent investigating the accident:__________________hours at average of S$___________/hour

33.3 Time spent with regulatory inspector, project owner, or news media as a result of accident: __________hours at average of S$____________/hour

34. Damaged equipment or plant, property, material or finished work

34.1 Costs of damaged property, material or finished work, excluding those covered by insurance policy: S$______________________

34.2 Was any productive time lost (e.g. interruption of production) because of damage to equipment, property or finished work?

[ ] No;

[ ] Yes, the number of hours lost were_____________hours at an average hourly cost of S$ __________________/hour.

35. **Estimated cost of transporting injured worker: S$________________**

36. **Estimated consumption of first-aid materials in this accident: S$_________________**

37. **Any additional work required as a result of the accident? (e.g. cleaning, additional barriers and so on)**

[ ] No;

[ ] Yes, the number of hours lost were______________at an average hourly cost of S$ _________________/hour.

38. **Fines and legal expenses**

38.1 Fines by government or court due to the accident: S$________________________

38.2 Legal fees and other administrative costs: S$___________________________

39. **Losses due to Stop Work Orders (SWO) issued to the project**

39.1 Wages paid to workers during the period of Stop Work:____________________days

39.2 Liquidated damages due to the SWO:____________________days

40. **The number of Demerit points awarded due to the accident:____________________**

41. **Was there any additional benefits/compensation to the injured worker beyond the Work Injury Compensation Act?**

[ ] No;

[ ] Yes, please specify the costs: S$____________________

Section E: Project Hazard Level

42. **Please rate the level of hazard posed by the following parameters in various works of this project. Please tick your responses below using the following scale:**

1 – Very low; 2 – Low; 3 – Ordinary level; 4 – High; 5 – Very high

Parameters and works	**1**	**2**	**3**	**4**	**5**
(1) Demolition works					
Volume/size of demolition	1	2	3	4	5
Type of structure	1	2	3	4	5

Parameters and works	**1**	**2**	**3**	**4**	**5**
Method of demolition	1	2	3	4	5
(2) Excavation works					
Excavation configuration (depth, width and length)	1	2	3	4	5
Geological condition (soil type, water table, etc.)	1	2	3	4	5
Underground utilities (electrical, water and sewer lines)	1	2	3	4	5
Nearby vehicular traffic (vibration and surcharge)	1	2	3	4	5
Nearby building & structures (distance and height)	1	2	3	4	5
(3) Scaffolding and ladder usage					
Volume of scaffolding & ladder usage	1	2	3	4	5
Height of the scaffold/ladder that is to be used	1	2	3	4	5
Design (Type of material, member size, bracing, guardrails, platform size, toe board)	1	2	3	4	5
(4) Temporary structures					
Volume of temporary structures involved in the project	1	2	3	4	5
Design (Material, member size, bracing, guardrails, platform size, toe board)	1	2	3	4	5
(5) Roof works					
Volume of roofing involved	1	2	3	4	5
Height of the roof	1	2	3	4	5
Roofing material property such as slippery, brittleness, asbestos, etc.	1	2	3	4	5
Inclination of the roof	1	2	3	4	5
(6) Erection of steel/precast concrete structures					
Volume of erection work	1	2	3	4	5
Height of erection work	1	2	3	4	5
Erection method (partial/full erection at height, labour involvement level)	1	2	3	4	5
(7) Crane use					
Volume of lifting involved	1	2	3	4	5
Nature of materials lifted	1	2	3	4	5
Operating platform	1	2	3	4	5
Nature of site vicinity (nearby structures, overhead cables, etc.)	1	2	3	4	5
(8) Construction tools and machinery use					
Volume of plant and machinery used	1	2	3	4	5
Operating platform of plant and machinery (i.e. slope, etc.)	1	2	3	4	5
Site layout	1	2	3	4	5
Volume of tools used	1	2	3	4	5
Type of tools used	1	2	3	4	5
(9) Works on contaminated sites					
Type of contaminants on the site	1	2	3	4	5
Quantity of contaminants present	1	2	3	4	5
Duration of work on contaminated site	1	2	3	4	5
(10)Welding and cutting works					
The volume of welding & cutting works	1	2	3	4	5
Location of welding (confined space, underground, on ladders, etc.)	1	2	3	4	5

Parameters and works	**1**	**2**	**3**	**4**	**5**
(11) Works in confined spaces					
☐ The volume of confined space works	1	2	3	4	5
☐ Confined space configuration	1	2	3	4	5
☐ Type of activity to be involved (e.g. welding, waterproofing, etc.)	1	2	3	4	5
☐ Current usage of the confined space (if any)	1	2	3	4	5

Section F: Safety Culture of the Project

43. Please indicate to what extent you agree or disagree with each of the following statements based on the safety practices in this project by ticking your responses using the following scale:

1 – Strongly disagree; 2 – Disagree; 3 – Neutral; 4 – Agree; 5 – Strongly agree

Statements	**1**	**2**	**3**	**4**	**5**
(1) Management Commitment					
☐ Top management considers safety to be more important than productivity	1	2	3	4	5
☐ Management acts only after accidents have occurred	1	2	3	4	5
☐ Management praises site employees for working safely	1	2	3	4	5
☐ Management penalizes site employees for working unsafely	1	2	3	4	5
(2) Communication and Feedback					
☐ Management clearly communicates safety issues to all levels within the organisation	1	2	3	4	5
☐ Management operates an open-door policy on safety issues	1	2	3	4	5
☐ Management encourages feedback from site employees on safety issues	1	2	3	4	5
☐ Management listens to and acts upon feedback from site employees	1	2	3	4	5
☐ Management communicates lessons from accidents to improve safety performance	1	2	3	4	5
(3) Supervisory Environment					
☐ Site management and supervisors see themselves as safety role models for all workers.	1	2	3	4	5
☐ Supervisor/safety officer usually engages in regular safety talks.	1	2	3	4	5
☐ Supervisors endeavor to ensure that individuals are not working by themselves under risky or hazardous conditions.	1	2	3	4	5
☐ Supervisor/safety officer is a good resource for solving safety problems.	1	2	3	4	5
☐ Supervisors have positive safety behaviour.	1	2	3	4	5
(4) Supportive Environment					
☐ As a group, workers maintain good working relationships.	1	2	3	4	5
☐ Co-workers always offer help when needed to perform the job safely.	1	2	3	4	5
☐ Workers always remind each other on how to work safely.	1	2	3	4	5
☐ The communication between workers and supervisors is effective (no language barriers)	1	2	3	4	5
☐ The communication between workers and their co-workers is effective.	1	2	3	4	5

Statements	**1**	**2**	**3**	**4**	**5**
(5) Work Pressure					
☐ Workers always work under a great deal of tension, and not given enough time to get the job done safely.	1	2	3	4	5
☐ Under tight schedule, management tolerates minor unsafe behaviours performed by workers.	1	2	3	4	5
☐ The wages of workers are not determined solely by the amount of work completed by them	1	2	3	4	5
☐ Productivity targets are in conflict with some safety measures.	1	2	3	4	5
(6) Personal Appreciation of Risk					
☐ Everyone on site is clear about his/her responsibilities for safety.	1	2	3	4	5
☐ Everyone on site is aware that safety is the top priority in his/her mind while working	1	2	3	4	5
☐ Workers are willing to report the unsafe and unhealthy conditions on site.	1	2	3	4	5
☐ Workers have the right to refuse to work in unsafe and unhealthy conditions.	1	2	3	4	5
(7) Training and Competence level					
☐ There is adequate safety training to site management team, such as supervisors and project management team members.	1	2	3	4	5
☐ There is adequate safety certification & training for the operators in the project.	1	2	3	4	5
☐ Enough safety training is conducted for personnel receiving and handling hazardous chemicals.	1	2	3	4	5
☐ Enough in-house safety training and orientations for workers (including sub-contractors) on site.	1	2	3	4	5
☐ The designated persons of the permit-to-work systems have the appropriate certificates and experience.	1	2	3	4	5
☐ Workers are familiar (>1 year experience in similar type of work) with the type of work that they are doing in this project.	1	2	3	4	5
☐ Personnel are required to attend refresher and upgrading course on a regular basis to maintain and enhance their safety knowledge and awareness.	1	2	3	4	5
(8) Safety Rules and Procedures					
☐ Your project has a project-specific Health & Safety (H&S) plan	1	2	3	4	5
☐ The set of safety rules and regulations is reviewed or updated periodically (minimum once per year).	1	2	3	4	5
☐ The set of safety rules and regulations is understood by site supervisors.	1	2	3	4	5
☐ The set of safety rules and regulations is understood by workers.	1	2	3	4	5
☐ Permit-To-Work (PTW) systems are established and implemented.	1	2	3	4	5
☐ Emergency and initial response procedures were developed.	1	2	3	4	5
☐ There are procedures to ensure that the sub-contractors meet the site safety requirements.	1	2	3	4	5
☐ There is a system to record and monitor worker’s behaviour and/or attitude.	1	2	3	4	5
(9) Workers’ Involvement					
☐ Workers play an active role in identifying site hazards.	1	2	3	4	5

Statements	**1**	**2**	**3**	**4**	**5**
Workers report accidents, incidents, and potentially hazardous situations.	1	2	3	4	5
Workers are consulted when safety plan is compiled.	1	2	3	4	5
Workers are involved with Health and Safety (H&S) inspections.	1	2	3	4	5
(10) Appraisal of Work Hazards					
There is an established and implemented hazard analysis or risk assessment programme/plan.	1	2	3	4	5
Potential risks and consequences are identified prior to execution.	1	2	3	4	5
Control measures for risks identified are adequate.	1	2	3	4	5
The inspection systems for the following items in the project were adequate.					
■ Excavation by a competent person on a daily basis and after hazardous events (e.g. inclement weather).	1	2	3	4	5
■ Scaffolding by a scaffold supervisor on a weekly basis and after inclement weather.	1	2	3	4	5
■ Temporary structures by a PE or other competent person before, during and after casting and after inclement weather.	1	2	3	4	5
■ Demolition by a competent person on a daily basis and after inclement weather.	1	2	3	4	5
■ Material loading platform by a competent person on a regular basis and after inclement weather.	1	2	3	4	5
■ Temporary structures such as site office, canteen, site hoardings and concrete batching plant on a regular basis	1	2	3	4	5
■ Housekeeping of construction worksite	1	2	3	4	5
■ Housekeeping of canteen, quarters, toilets, washing facilities, and site offices	1	2	3	4	5
■ Housekeeping of storages for materials, tools and wastes	1	2	3	4	5
■ Inspection of machinery and tools	1	2	3	4	5

Section G Personal Information

44. Your name(Optional):____________________________

45. Designation: [ ] Top management; [ ] Project manager; [ ] Safety officer;

[ ] Safety supervisor; [ ] Others, please specify________________________

46. Years of working experience in construction industry_________________________Years

47. Contact No (optional): _________________________

48. Email (optional): ______________________________

Thank you for your kind assistance